

# **MARS – CheObs ed.\***

## **A Flexible Software Framework for Future Cherenkov Telescopes**

\* **M**odular **A**nalysis and **R**econstruction **S**oftware – **C**herenkov **O**bservatory edition

Thomas Bretz and Daniela Dorner  
presented by Pavel Binko

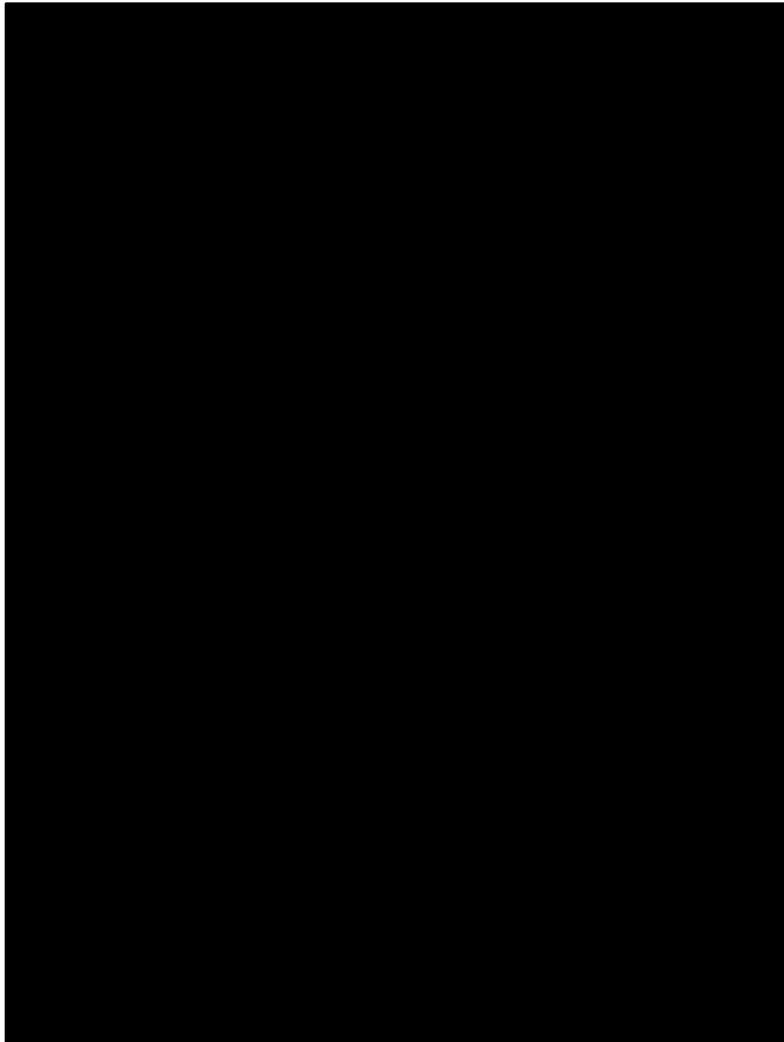
# Outline



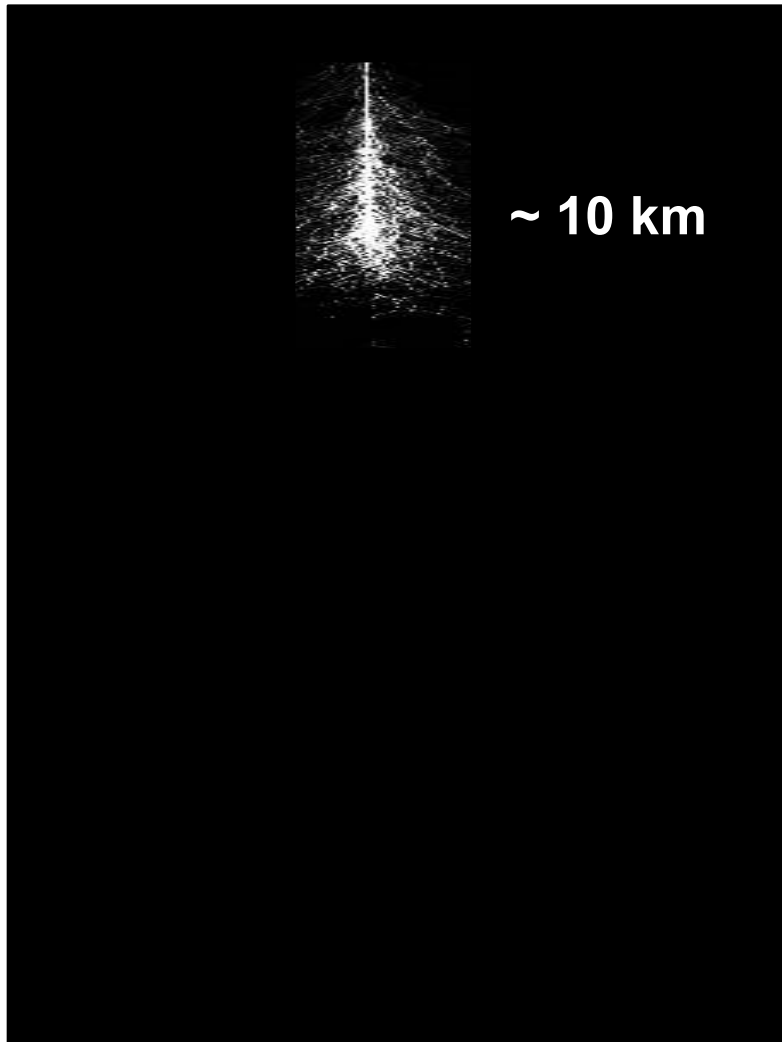
- Introduction:
  - Imaging Air Cherenkov Technique
  - Analysis Principles
  - Existing and future Cherenkov Telescopes
- DWARF Project
- Mars – CheObs ed.
  - Framework
  - Simulation
- Outlook

# Imaging Air Cherenkov Technique

Particle: gamma or cosmic ray

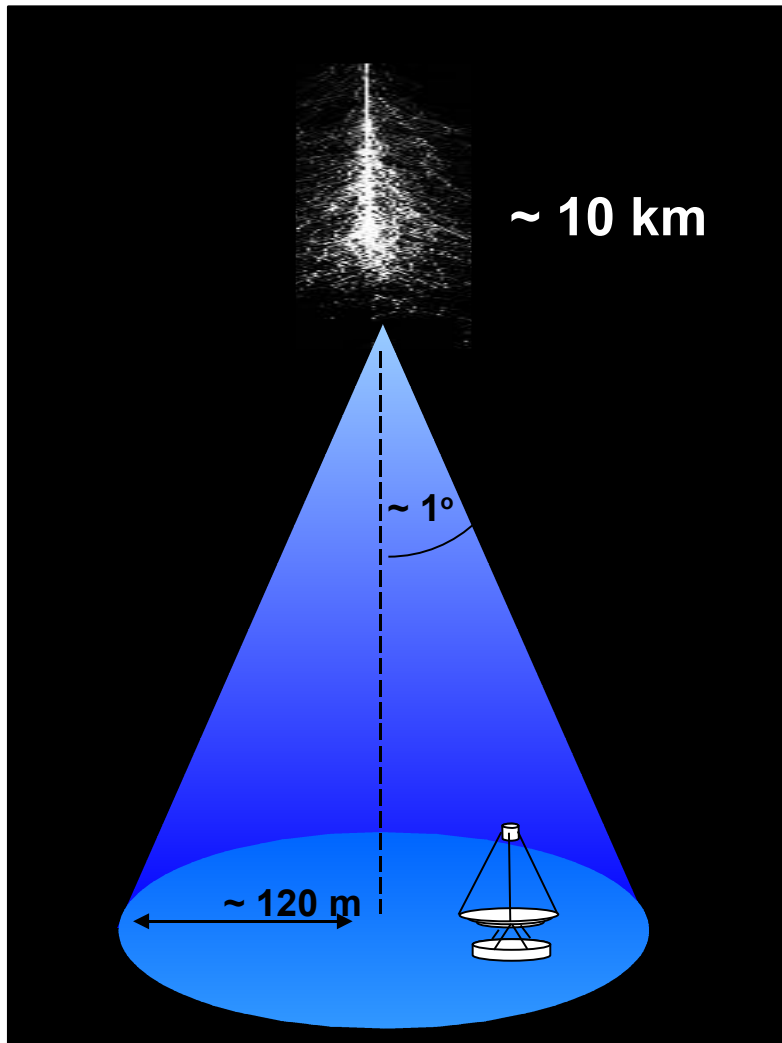


# Imaging Air Cherenkov Technique



Shower of  
secondary particles

# Imaging Air Cherenkov Technique



Emission of  
Cherenkov light

Light flashes of few  
nano-seconds

# Imaging Air Cherenkov Technique

1 Telescope => Mono Observations

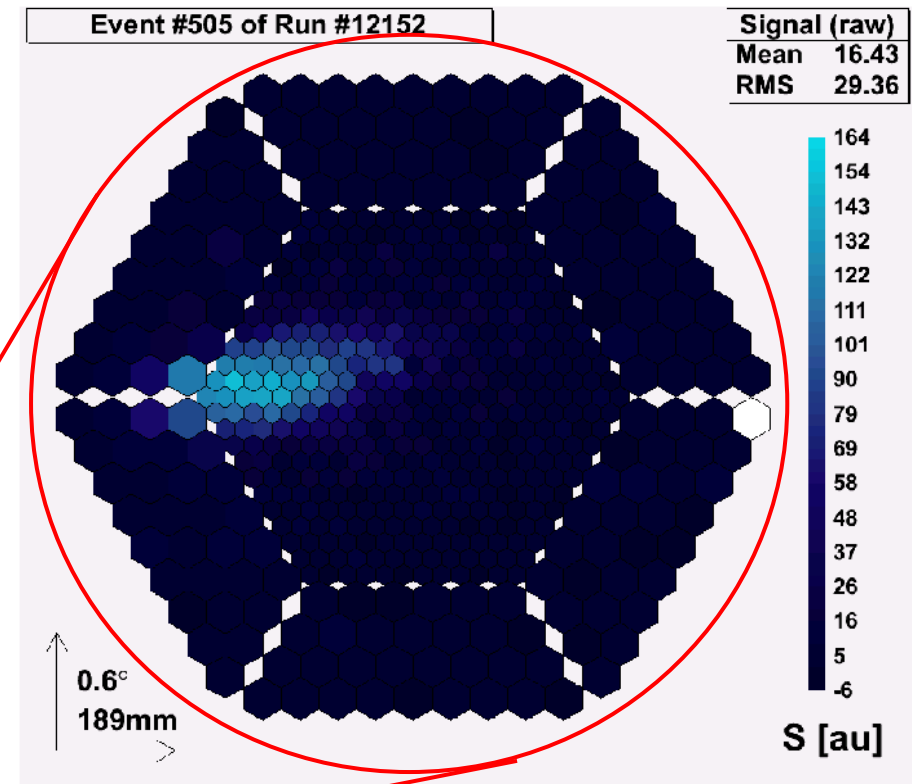
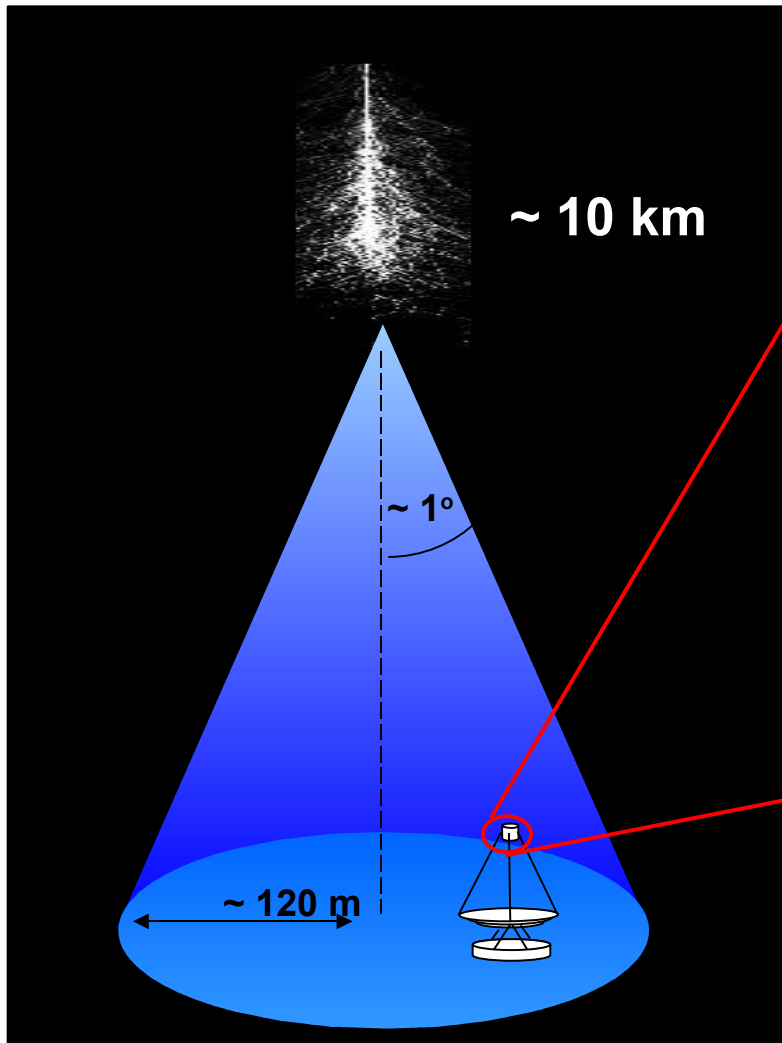
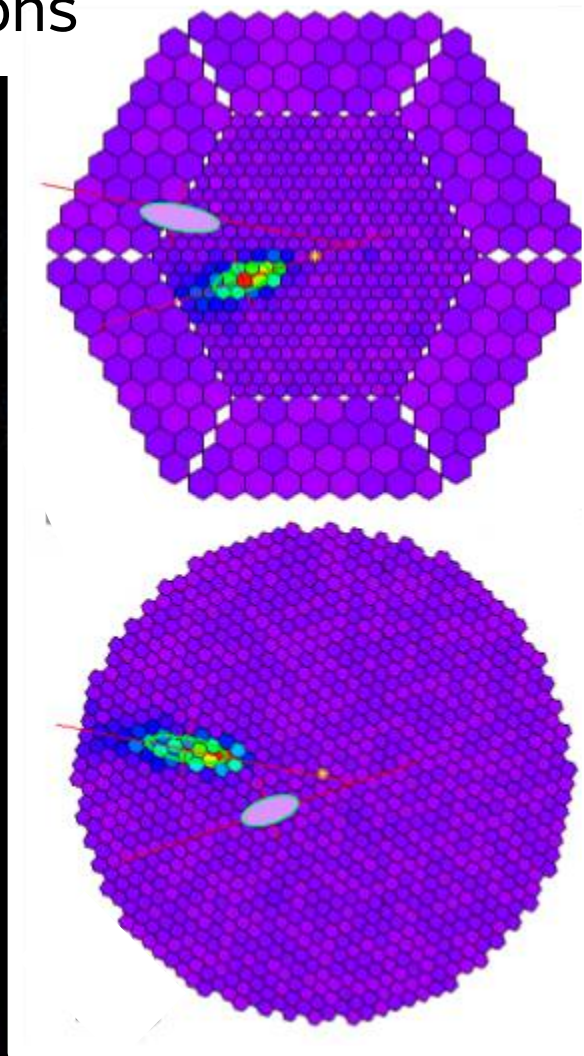
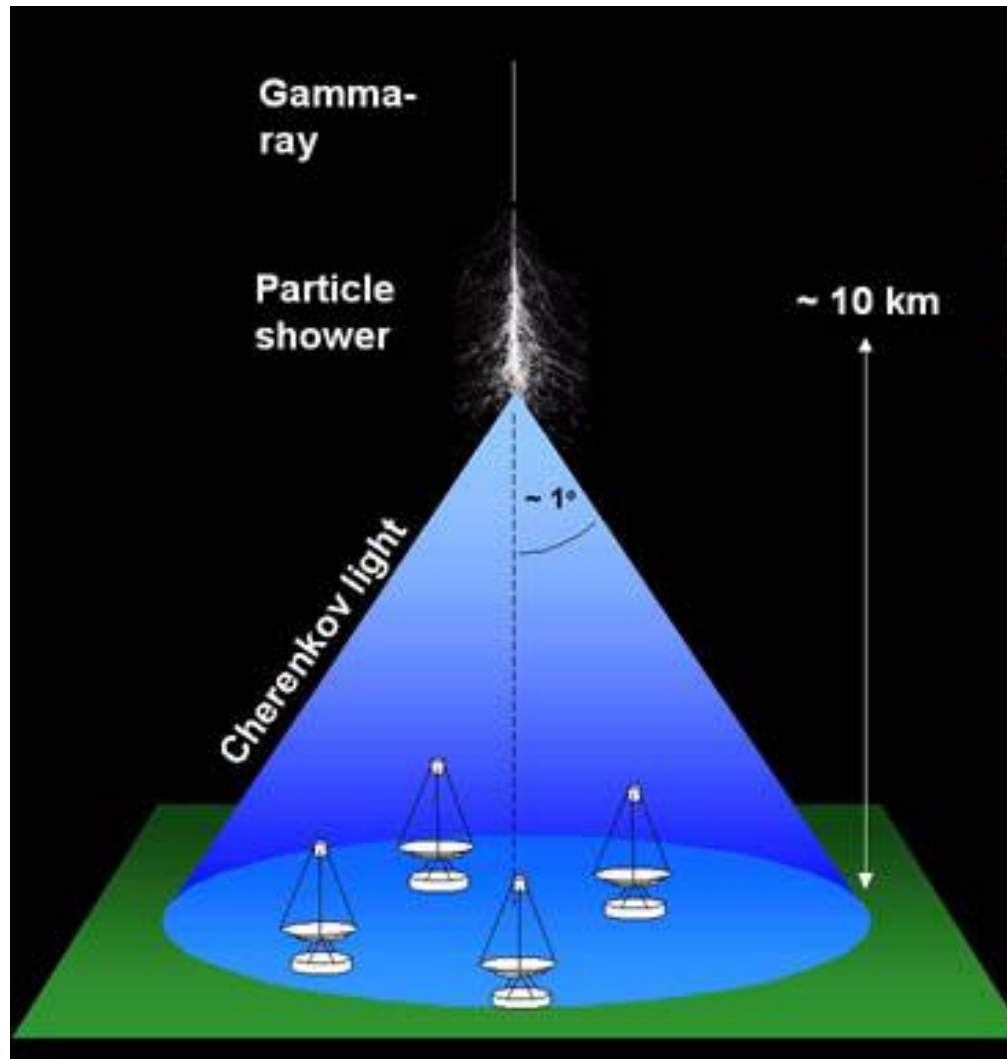


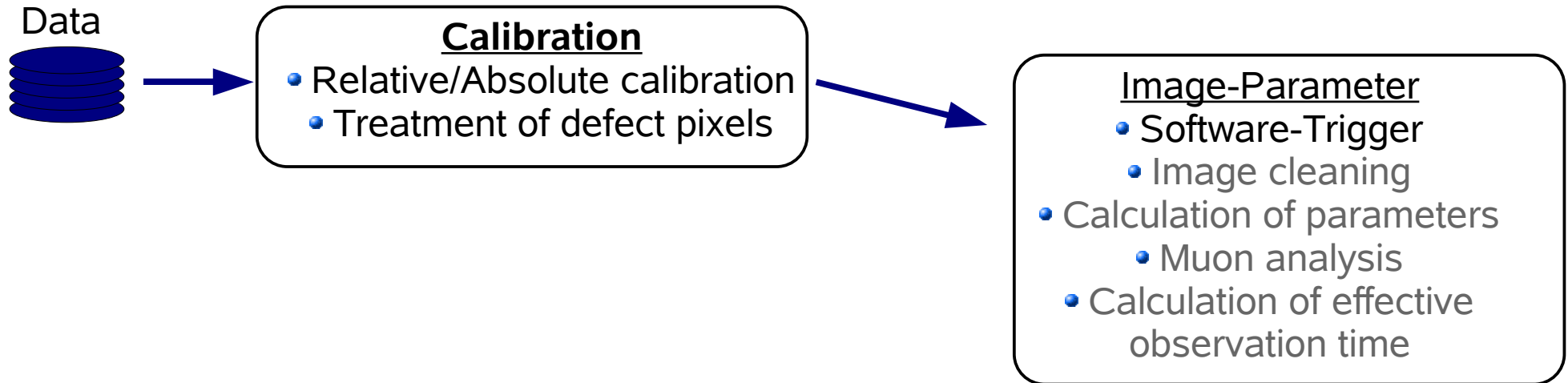
Image in the camera

# Imaging Air Cherenkov Technique

Array of Telescopes => Stereo Observations

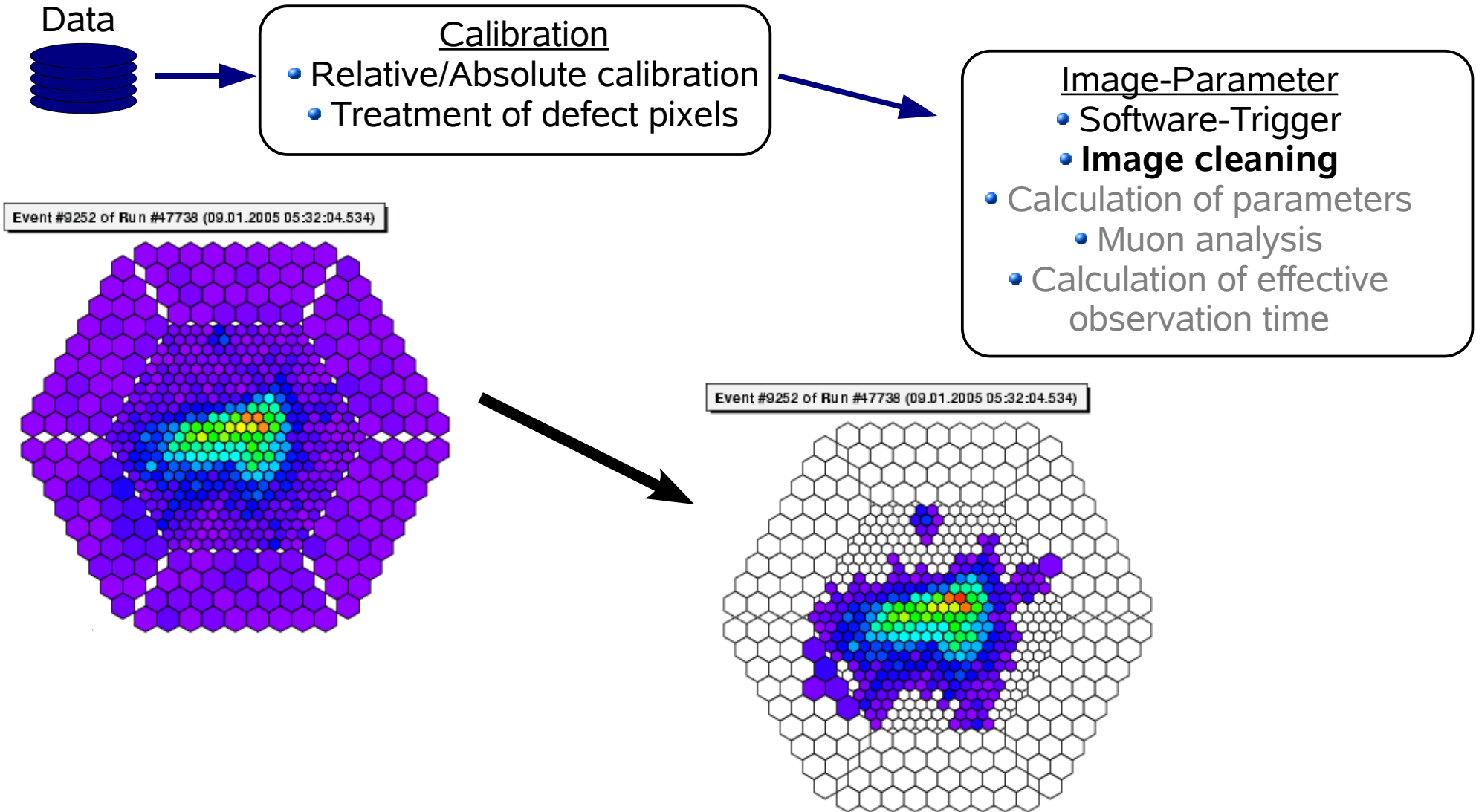


# Analysis Principles

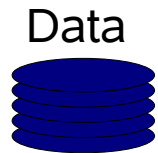




# Analysis Principles



# Analysis Principles



Data



## Calibration

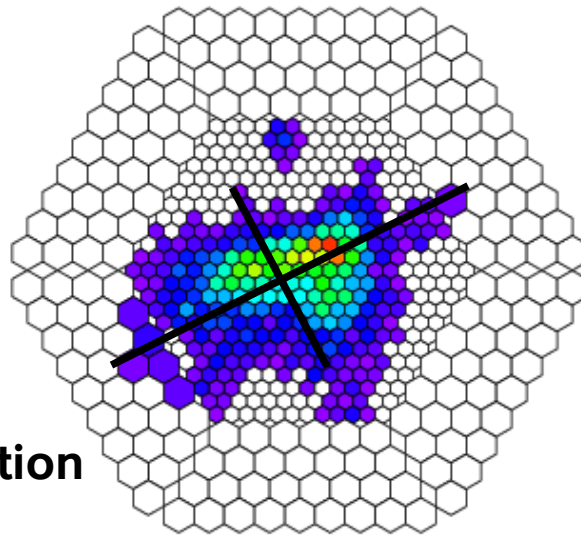
- Relative/Absolute calibration
- Treatment of defect pixels



## Image-Parameter

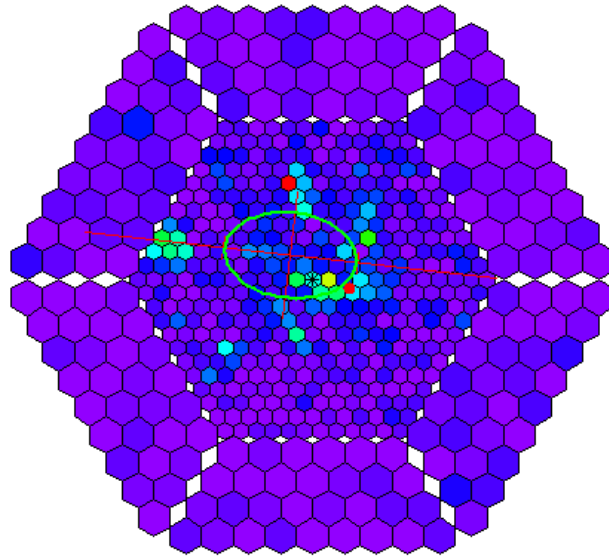
- Software-Trigger
- Image cleaning
- **Calculation of parameters**
  - Muon analysis
- Calculation of effective observation time

Event #9252 of Run #47738 (09.01.2005 05:32:04.534)

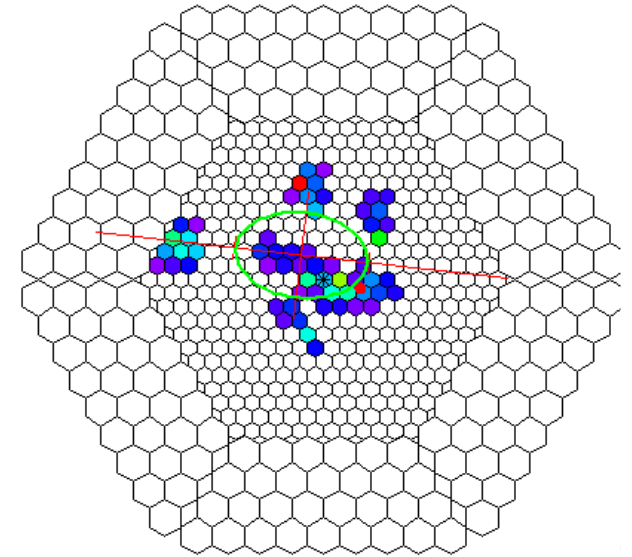


**Statistical analysis  
of the light distribution**  
(size, mean, rms)

**Different primary  
=> different shower  
morphology**

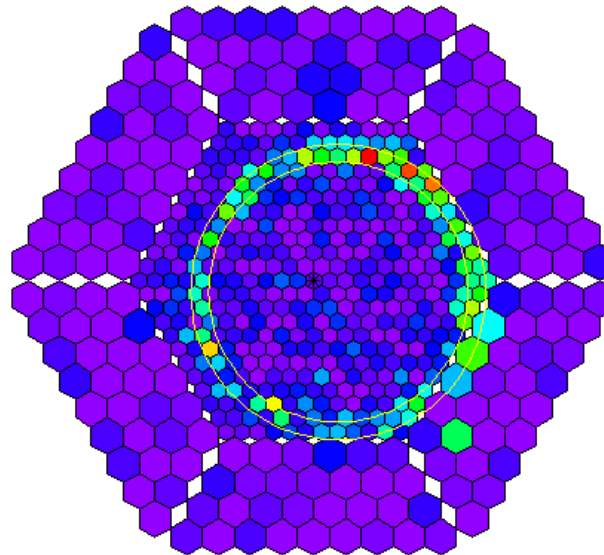


hadronic  
background



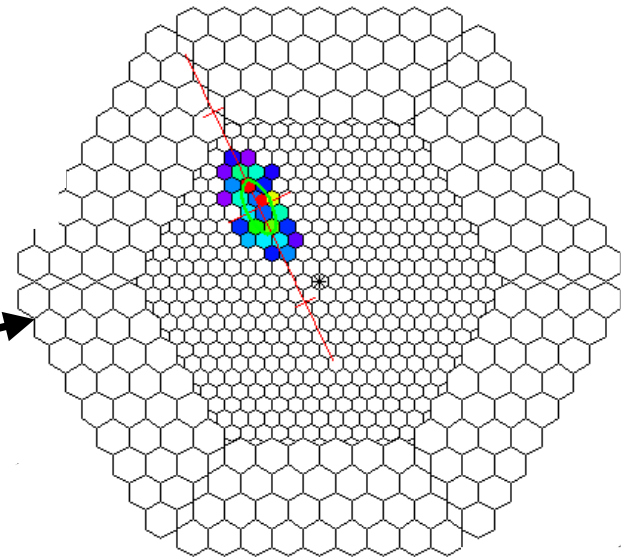
**gamma:background  
1:1000**

Event #9396 Filed #1:1000275/40 (29.05.2008 22:06:27.414)



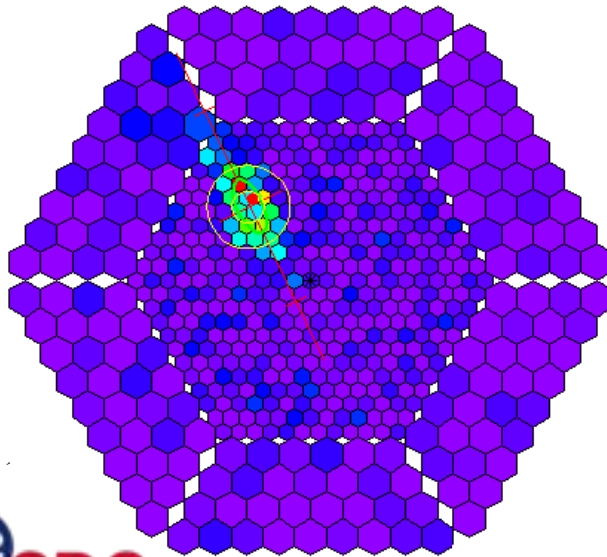
muon  
ring

Event #920 Filed #1:1000275/38 (29.05.2008 22:04:50.890)

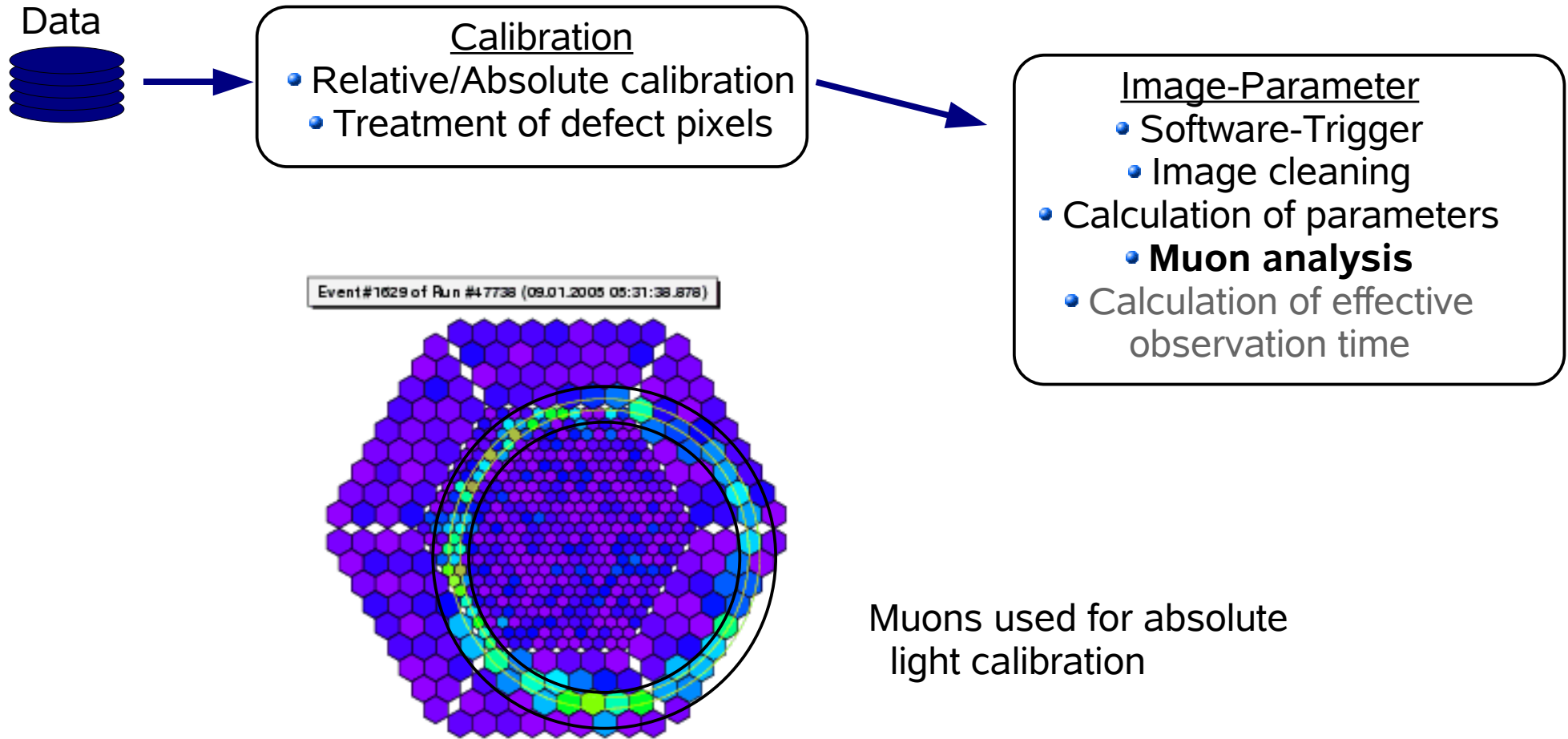


gamma  
candidate

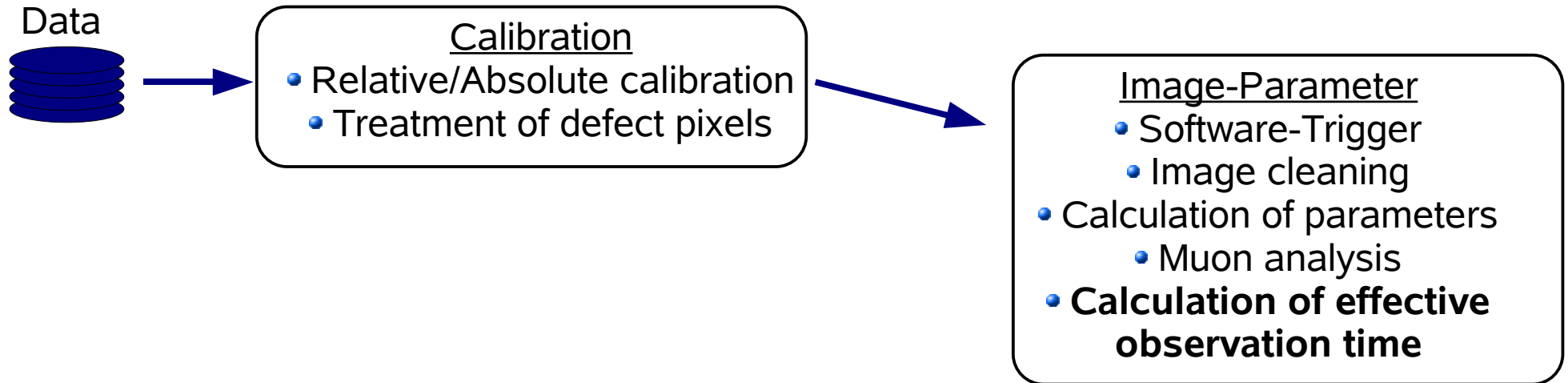
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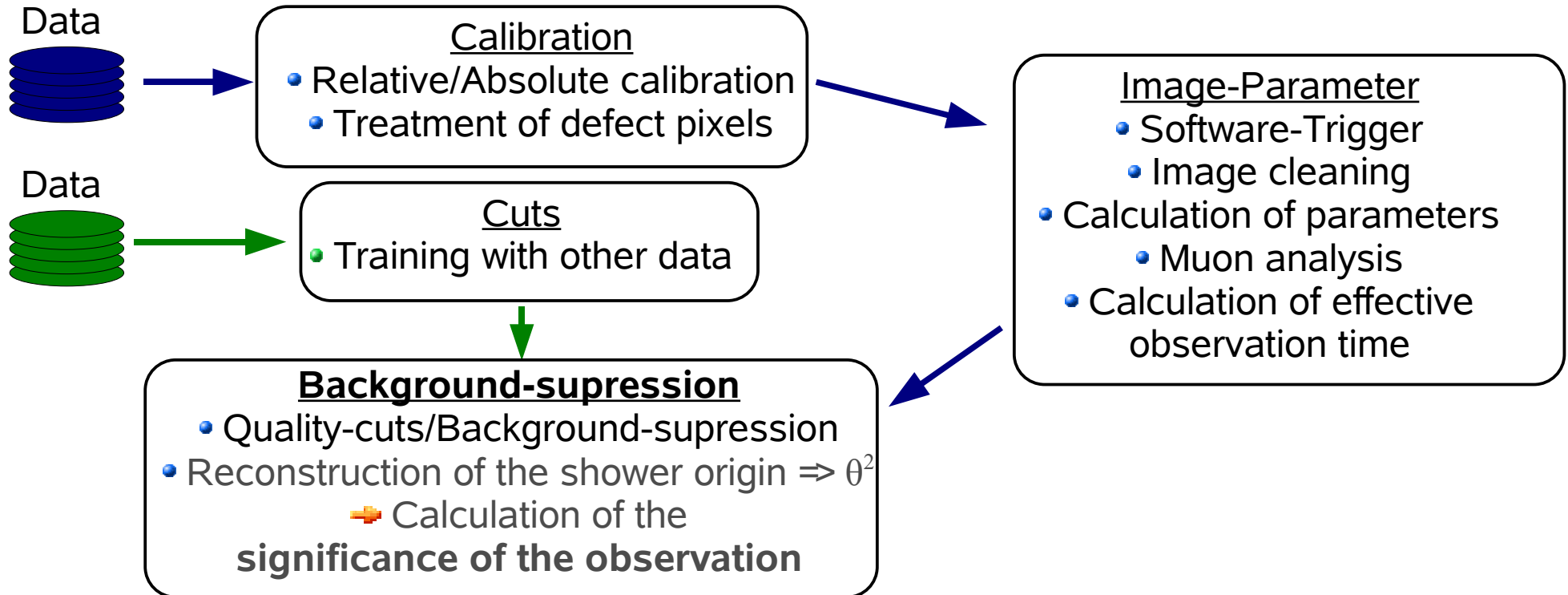
# Analysis Principles



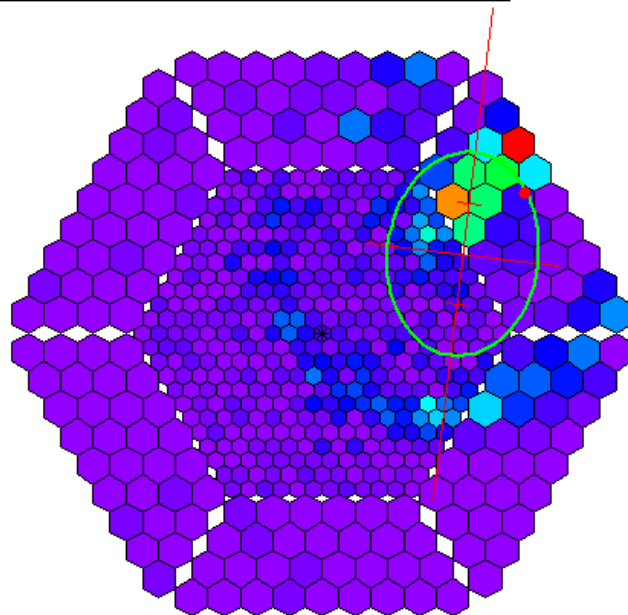
# Analysis Principles



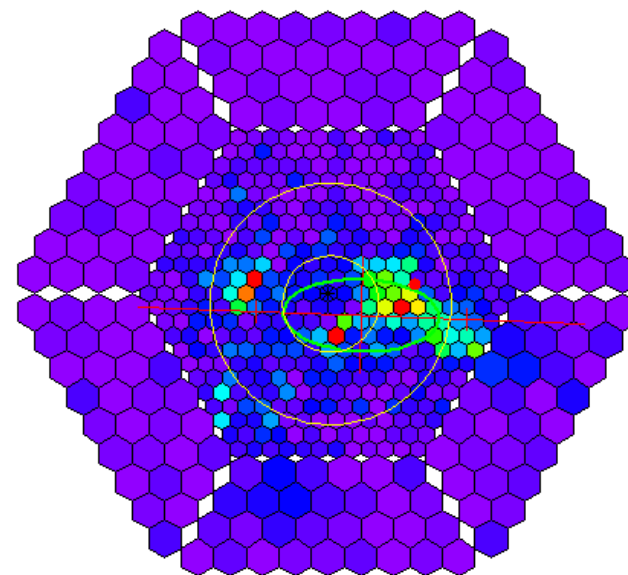
# Analysis Principles



Event #302 Fileid #1:1000275/38 (29.05.2008 22:04:50.166)

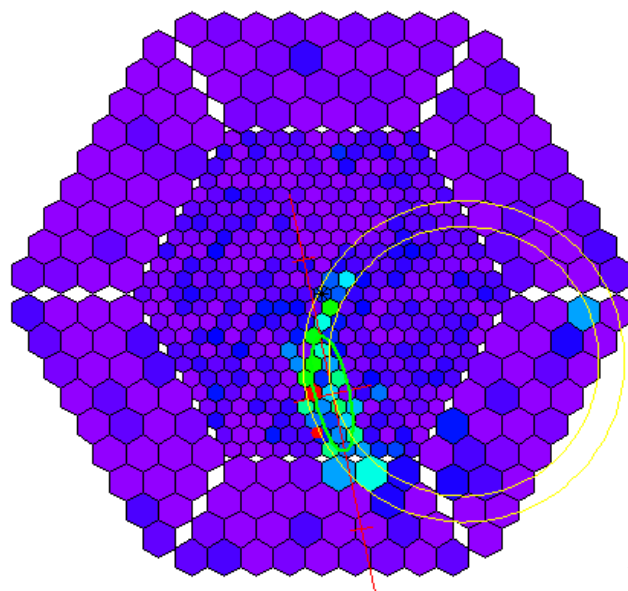


Event #2 Fileid #1:1000275/38 (29.05.2008 22:04:49.428)



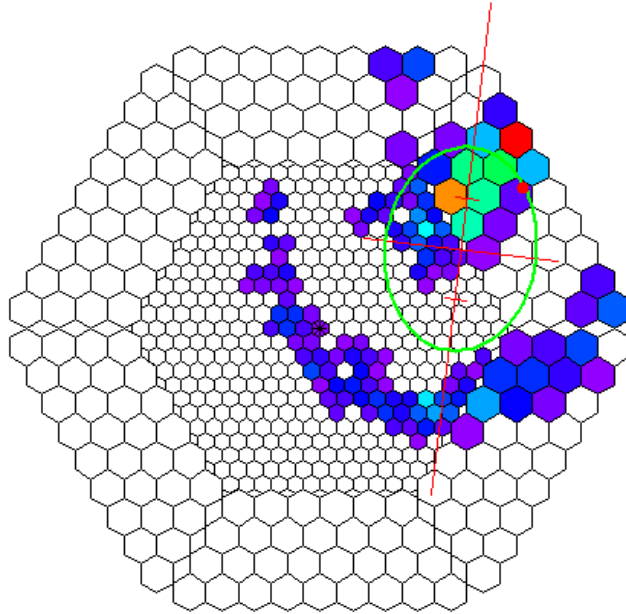
Background  
images

Event #76 Fileid #1:1000275/38 (29.05.2008 22:04:49.586)

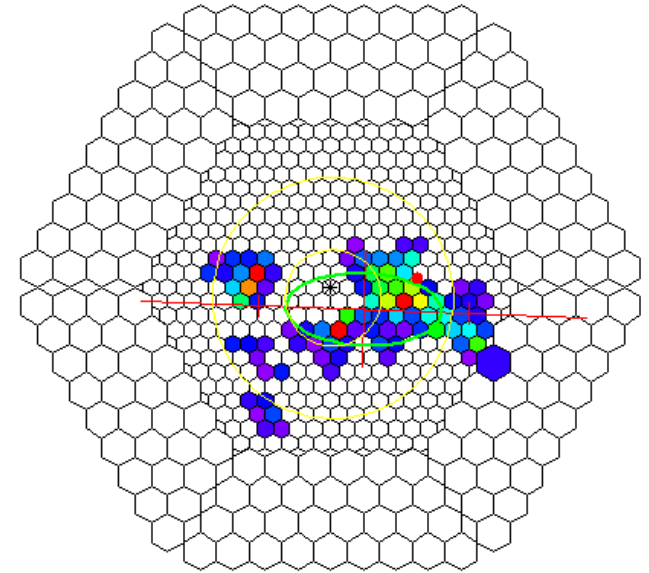




Event #302 Fileld #1:1000275/38 (29.05.2008 22:04:50.166)

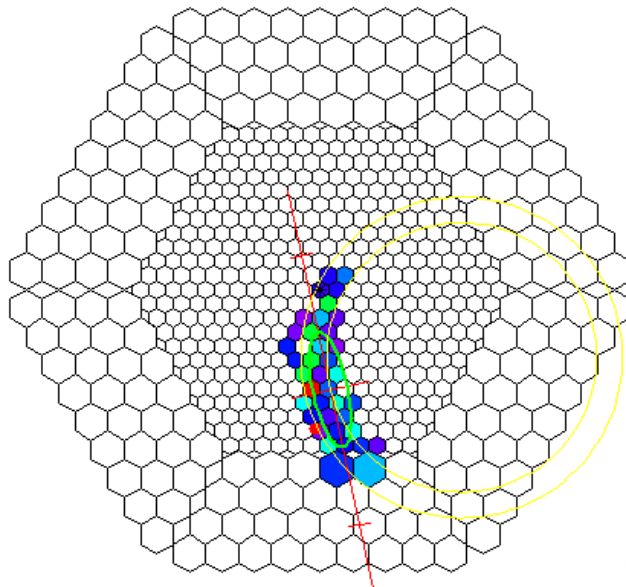


Event #2 Fileld #1:1000275/38 (29.05.2008 22:04:49.428)

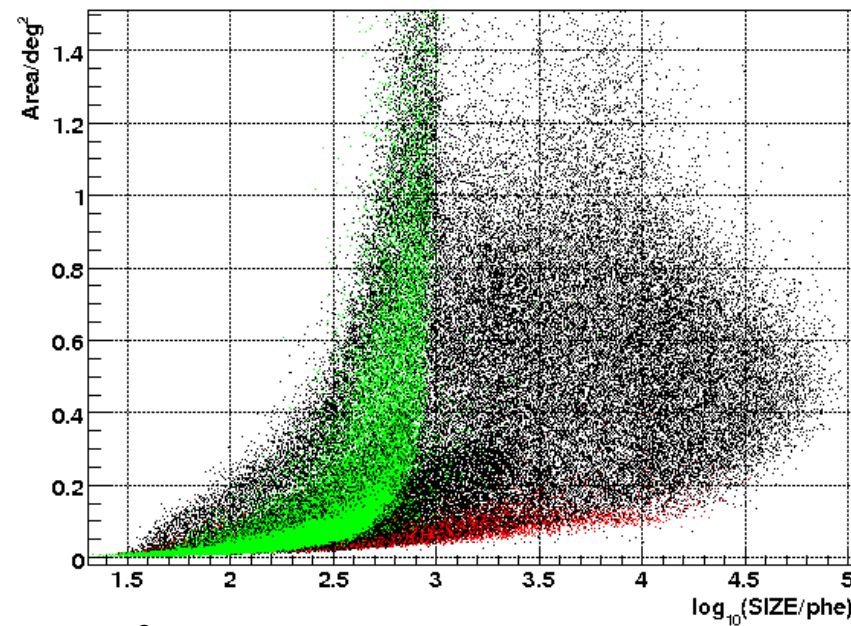


Background  
images

Event #76 Fileld #1:1000275/38 (29.05.2008 22:04:49.586)



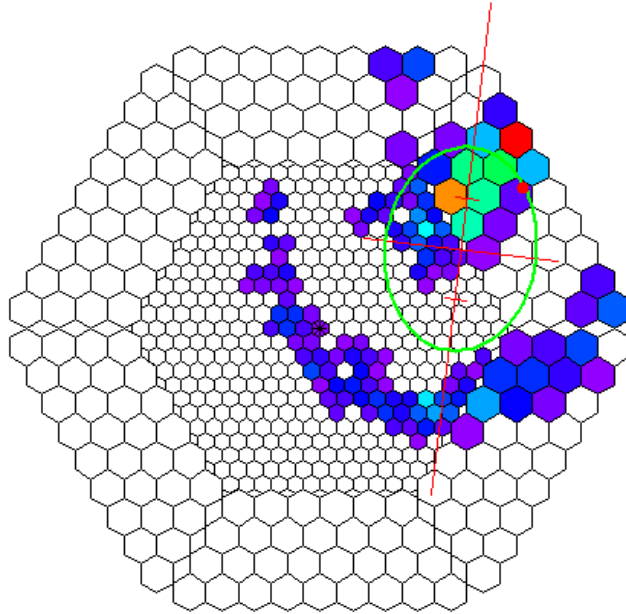
Distribution of image parameter



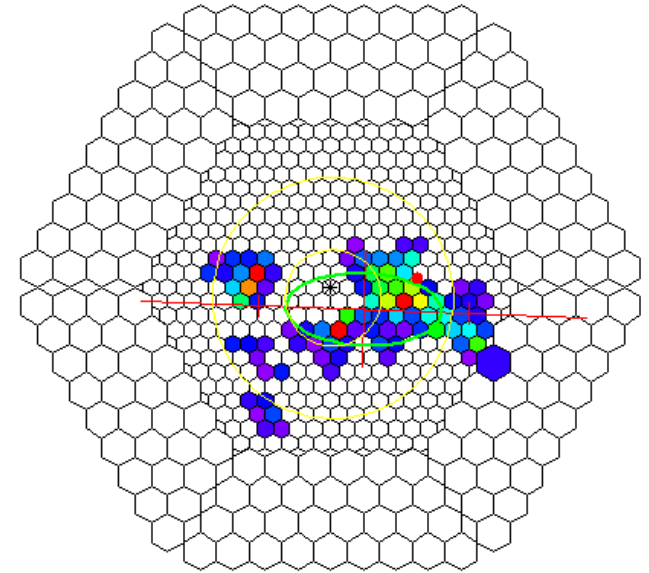
Real data  
Simulated  
muons  
Simulated  
gammas



Event #302 Fileid #1:1000275/38 (29.05.2008 22:04:50.166)



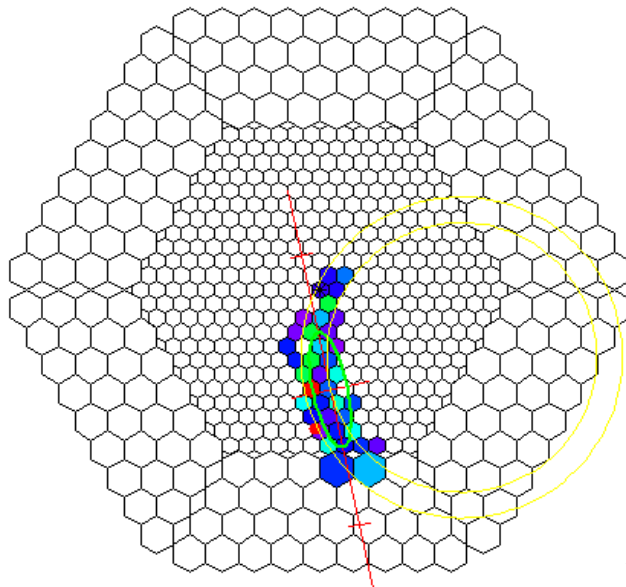
Event #2 Fileid #1:1000275/38 (29.05.2008 22:04:49.428)



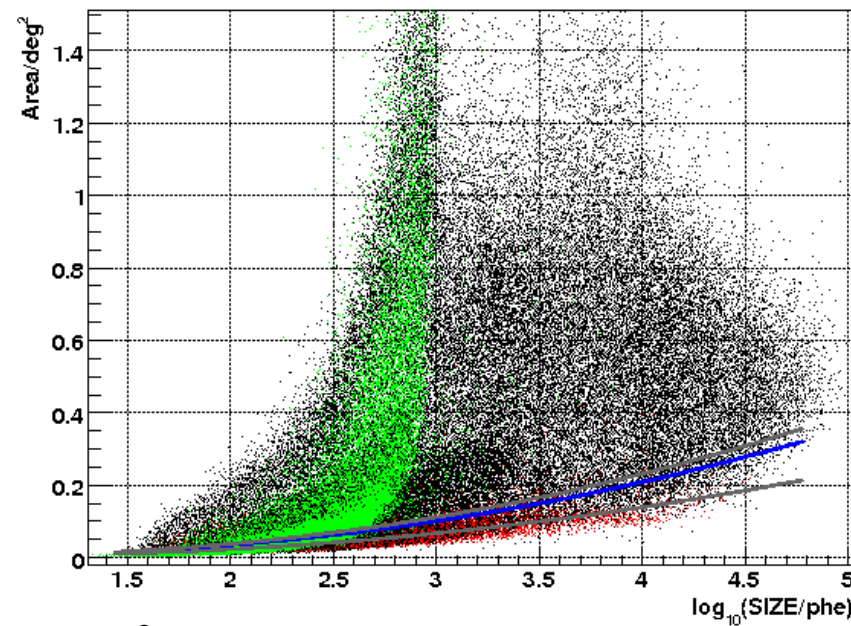
Background  
images

Discriminate  
Gammas from  
Background

Event #76 Fileid #1:1000275/38 (29.05.2008 22:04:49.586)

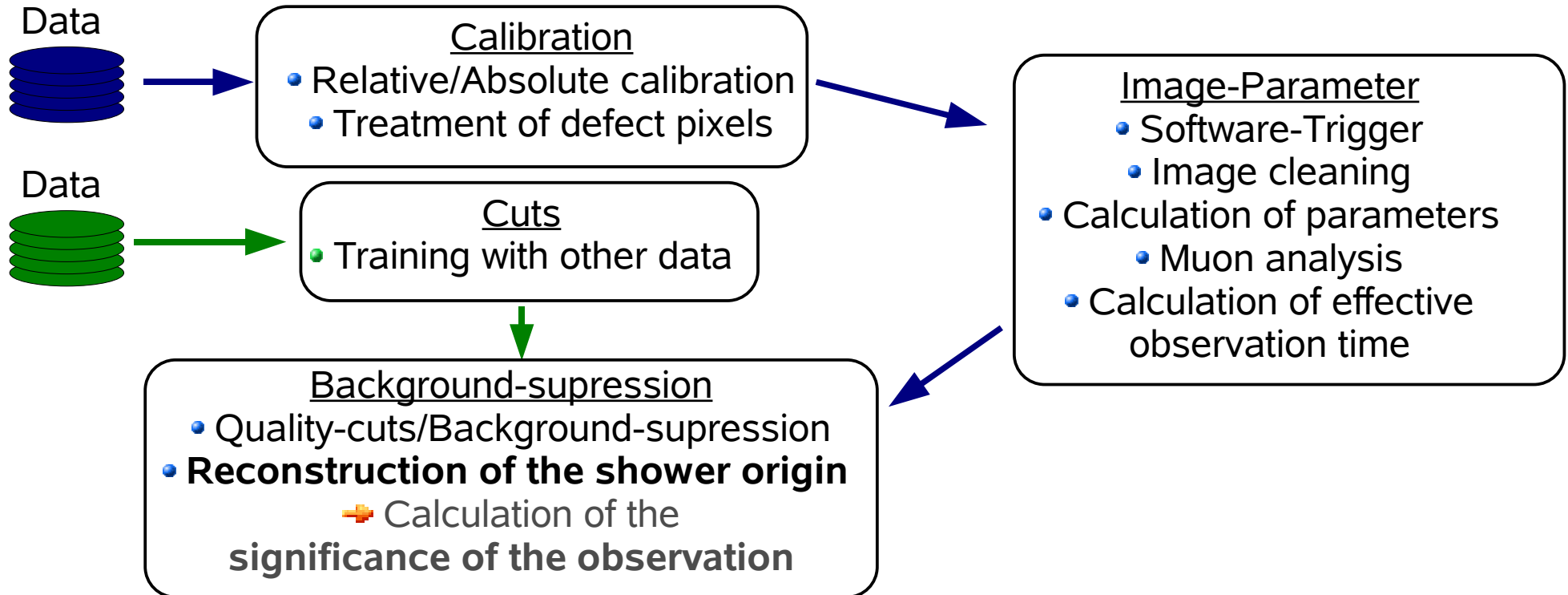


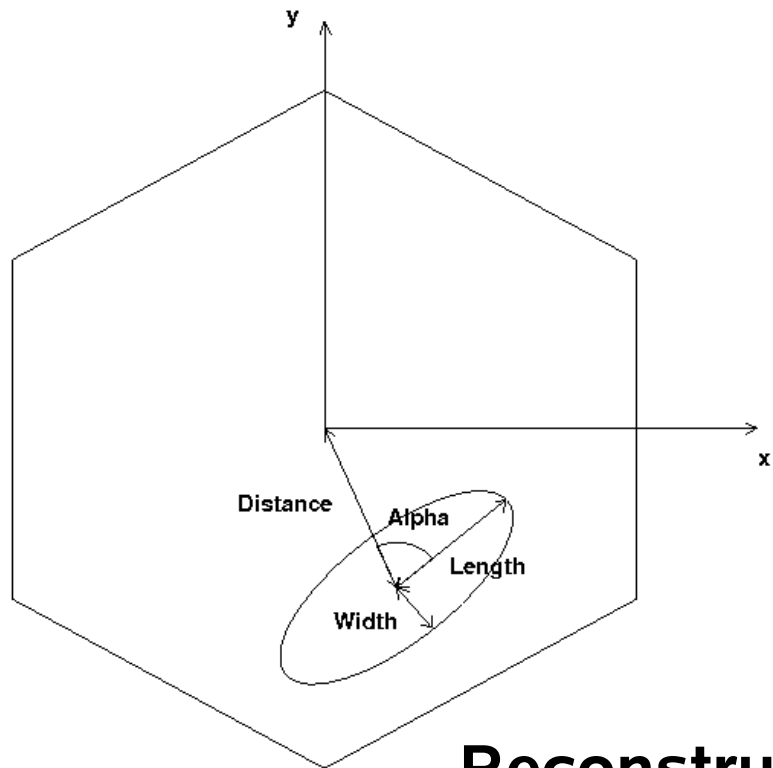
Distribution of image parameter => **cut**



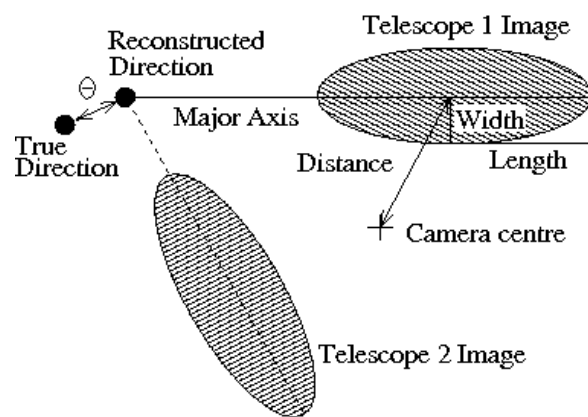
Real data  
Simulated  
muons  
Simulated  
gammas

# Analysis Principles



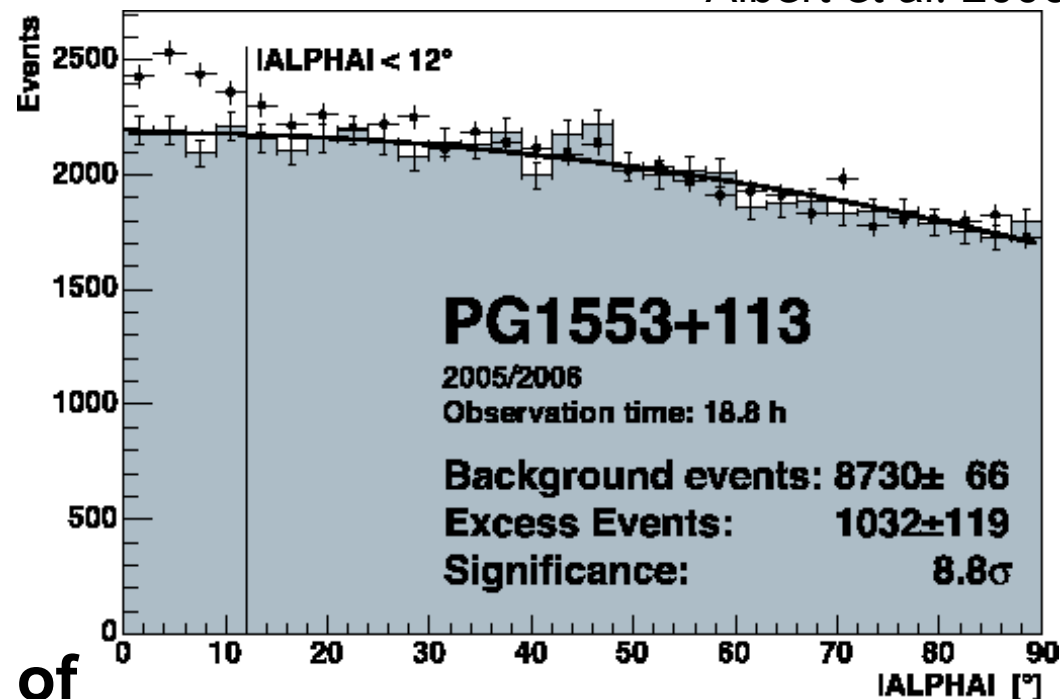


## Reconstruction of the shower origin



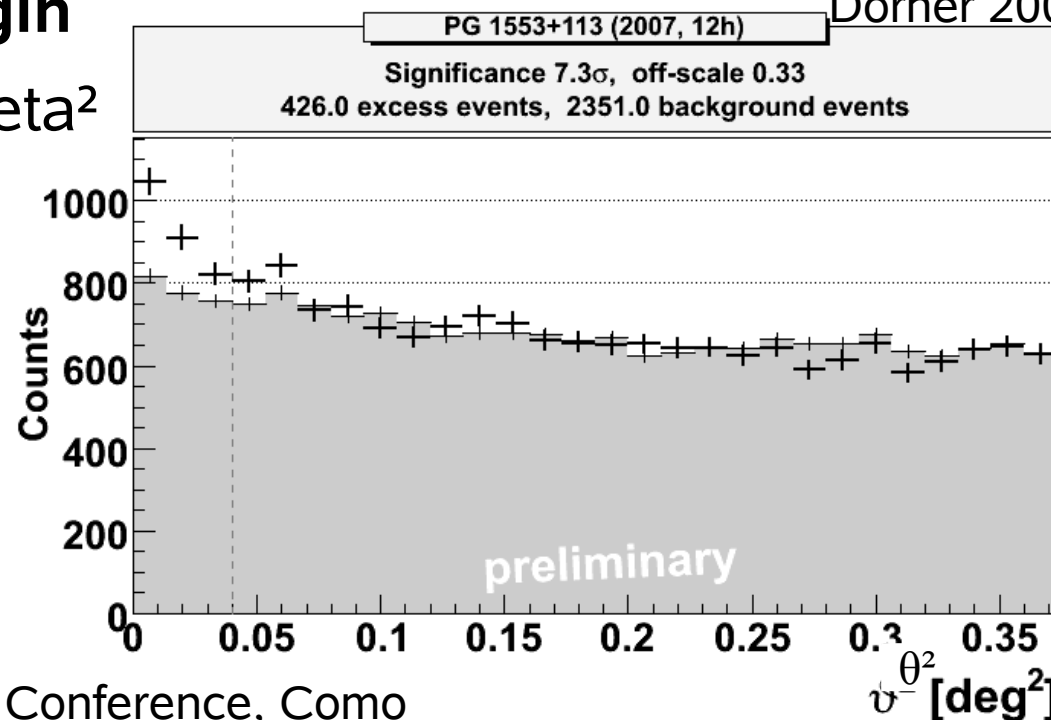
alpha

Albert et al. 2006

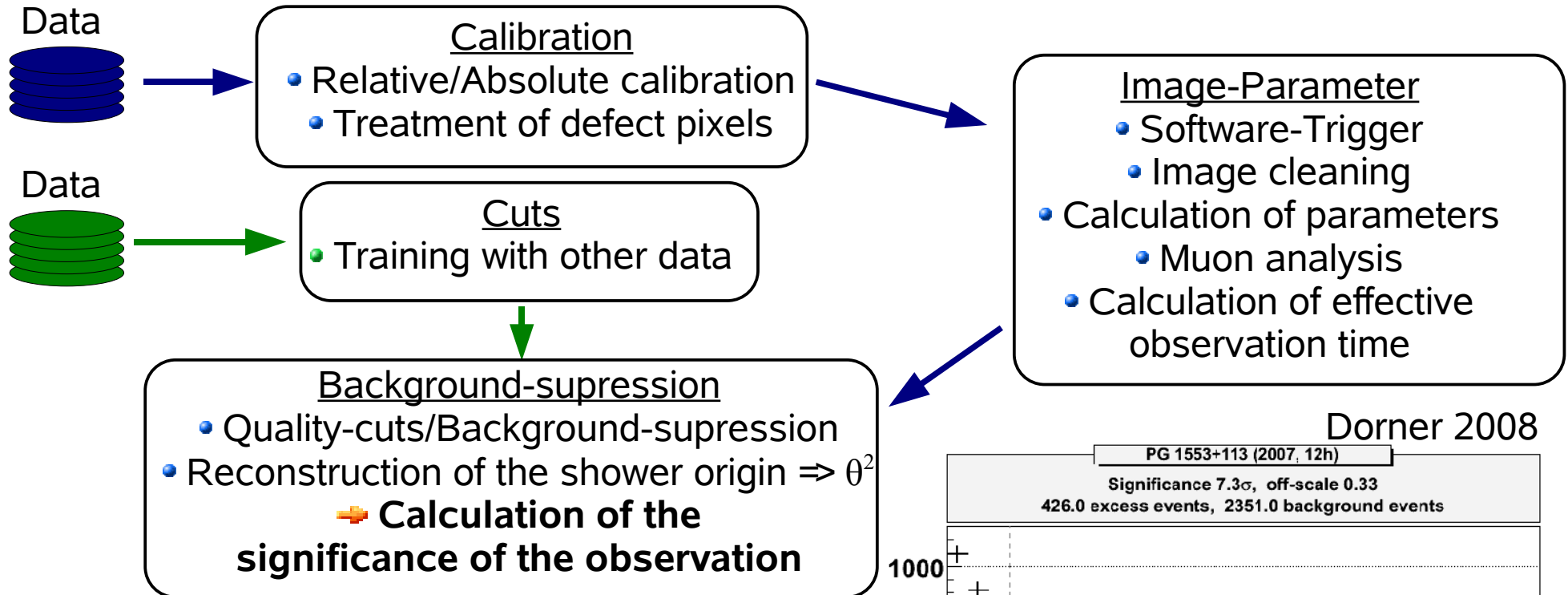


theta<sup>2</sup>

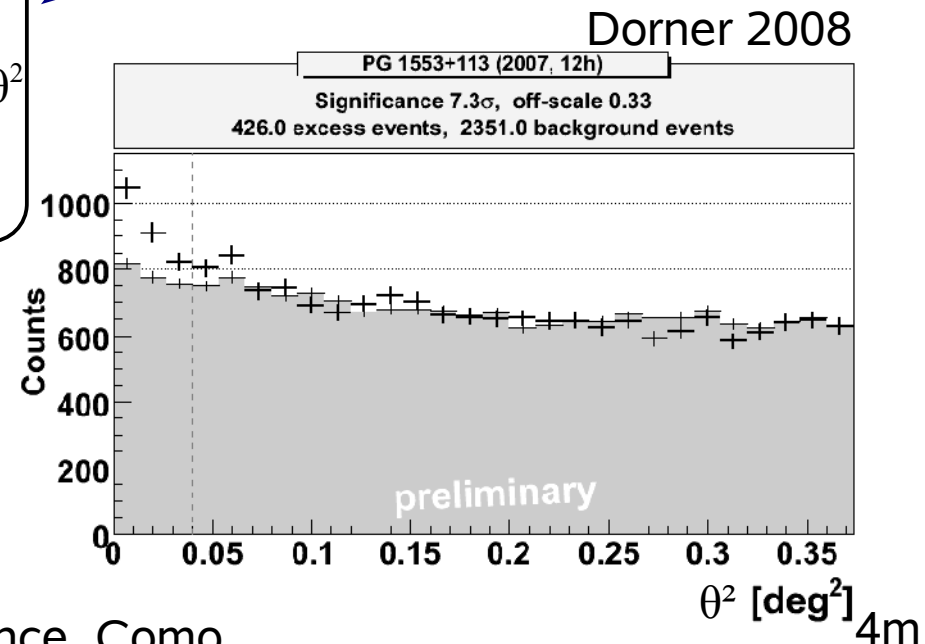
Dorner 2008



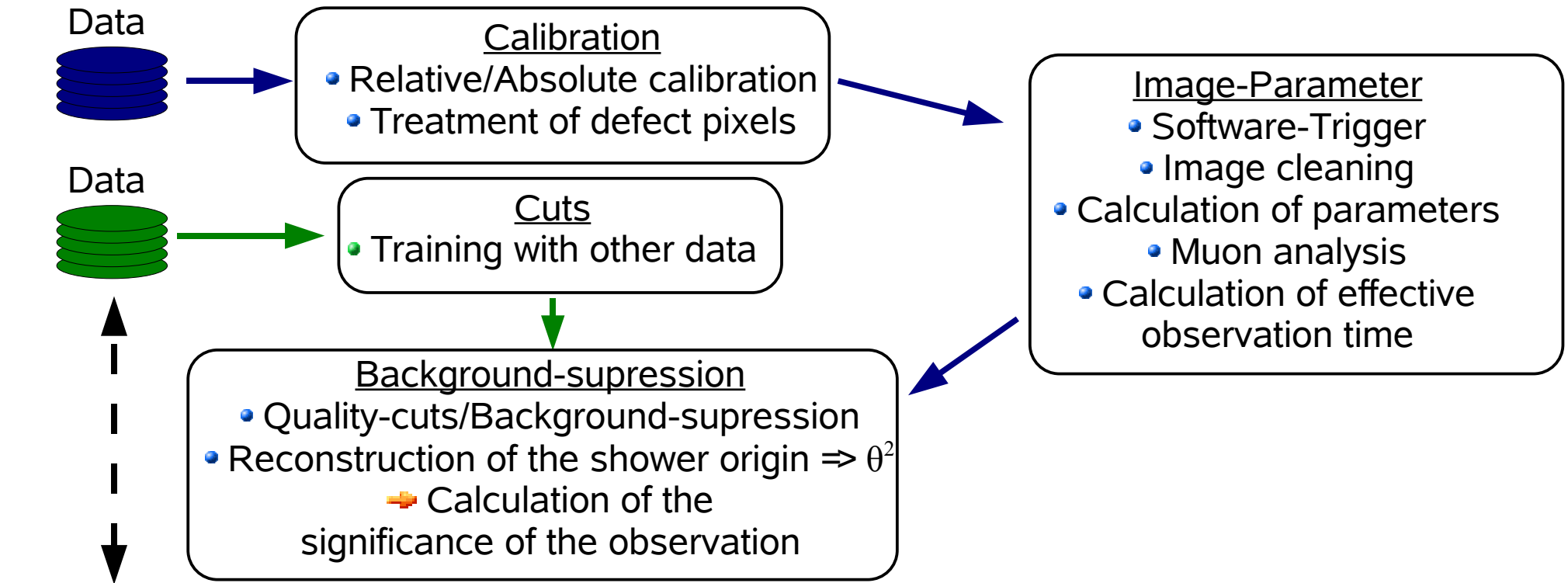
# Analysis Principles



Events from the source:  
 $\theta^2$  or  $\alpha$  values close to 0



# Analysis Principles



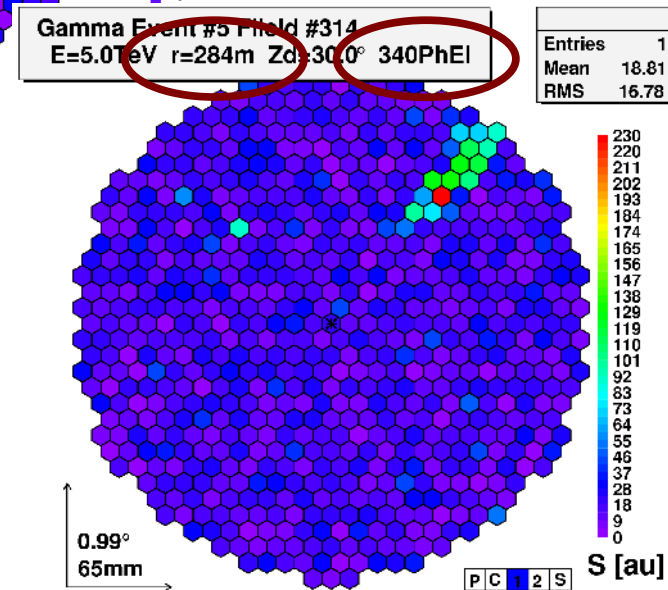
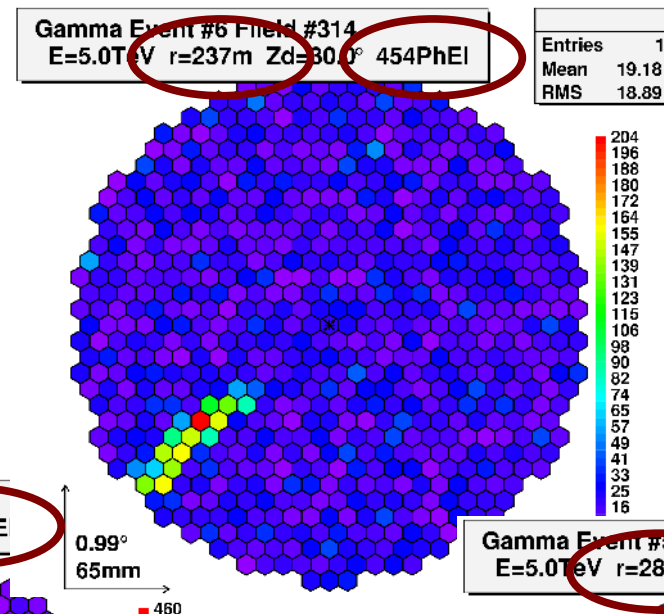
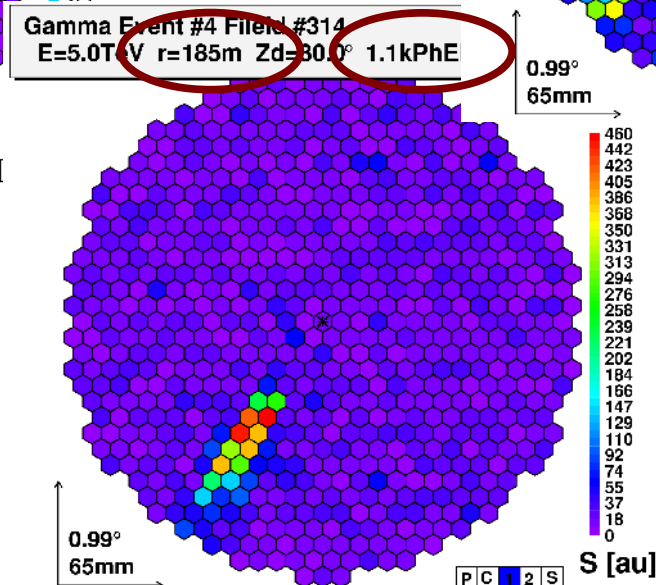
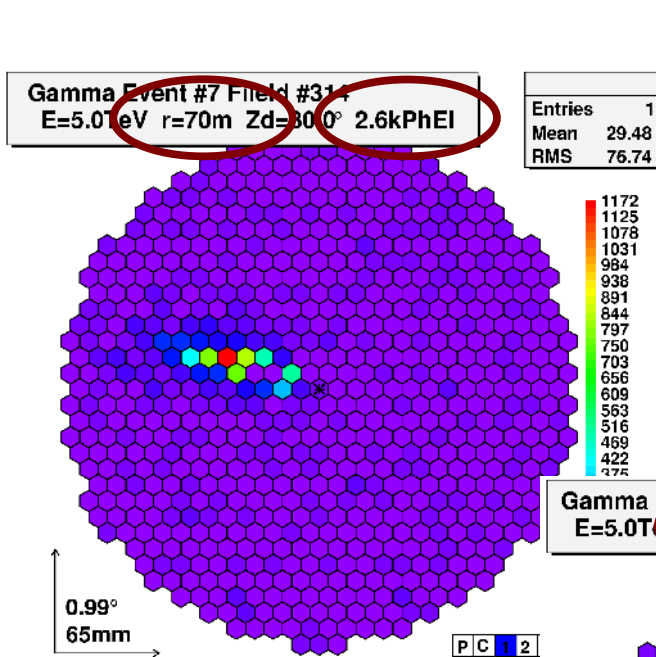
**Simulate** events with **same conditions like data:**  
psf, atmosphere, night sky background  
**Same analysis chain** like data  
 $\Rightarrow$  image parameters + energy of primary particle

# Energy Reconstruction using simulated events

Energy of the primary particle  $\propto$  shower size

Other influences: impact parameter, zenith angle, ...

=> reconstruct energy from parameters



Example from DWARF simulation:

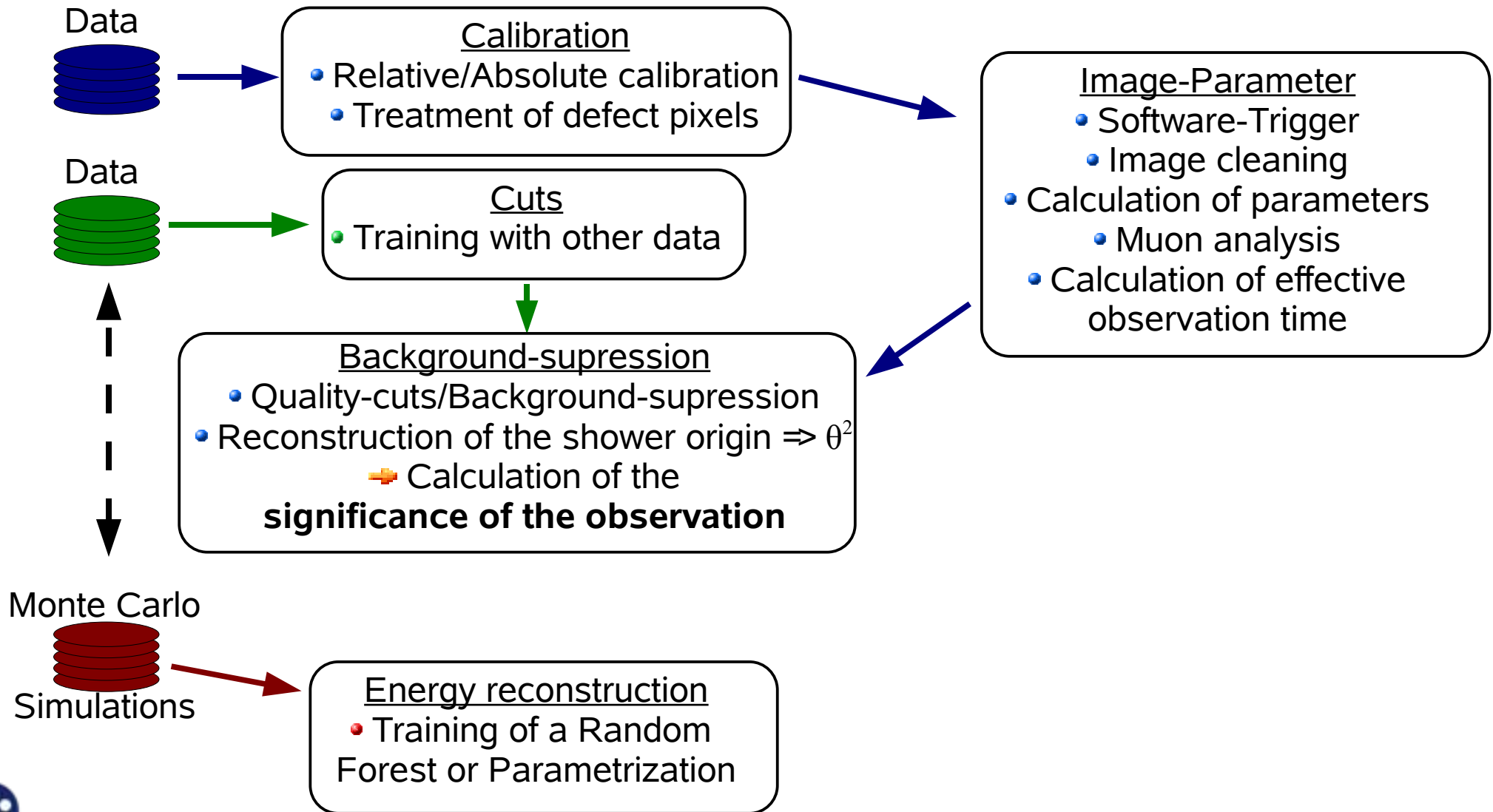
Simulated gamma events for different impact parameters

Same energy

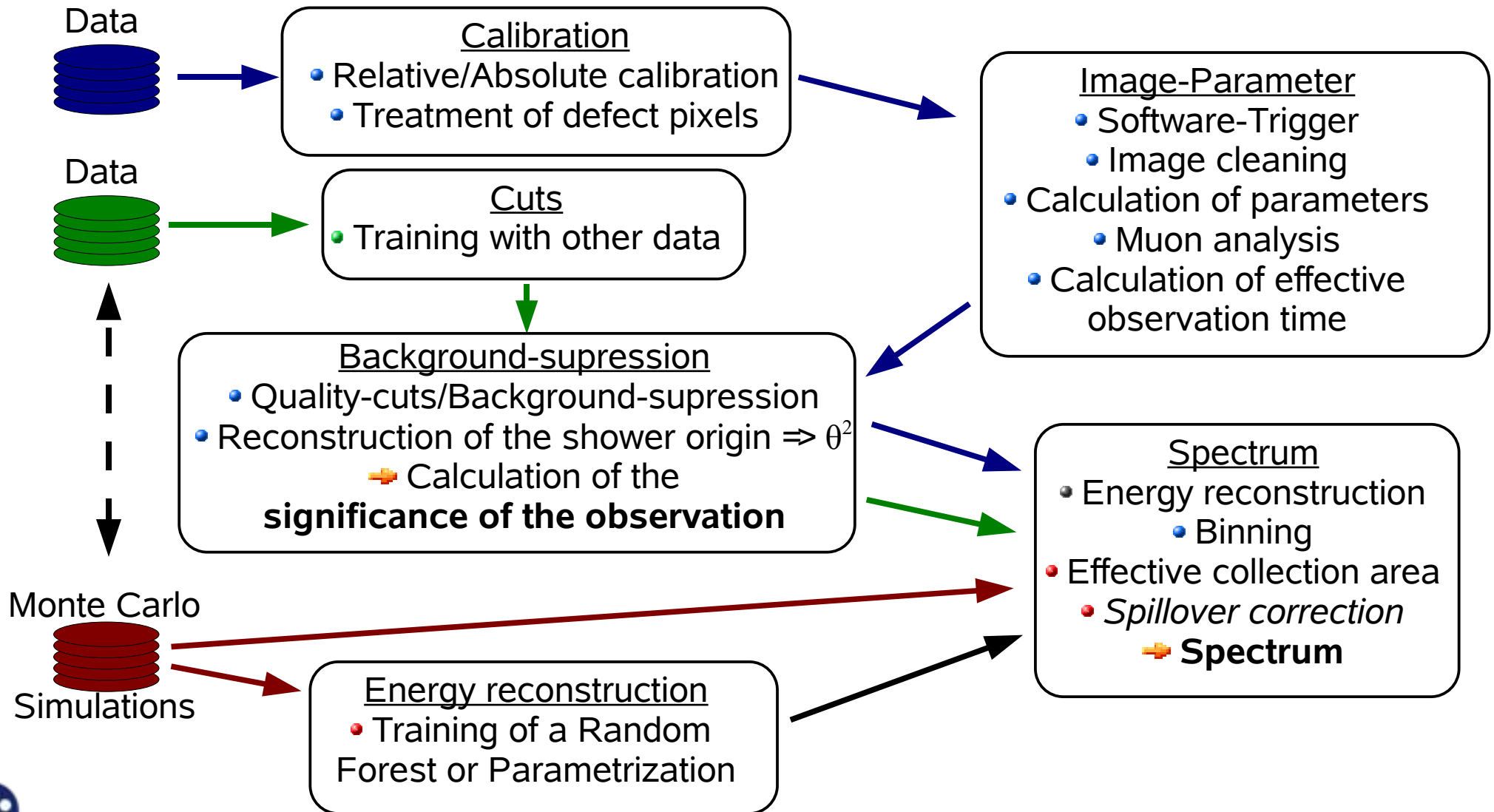
Different impact  
=> different distance  
=> different size



# Analysis Principles

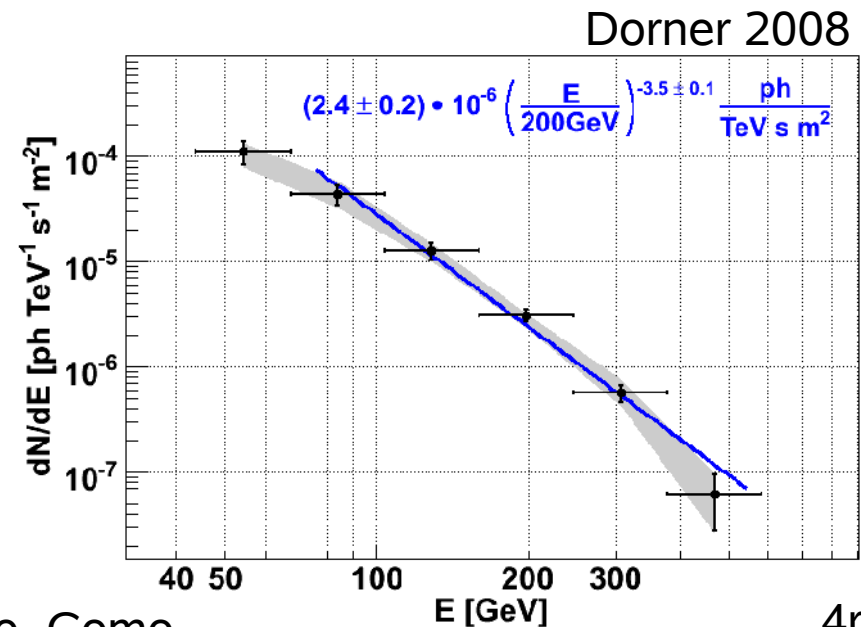
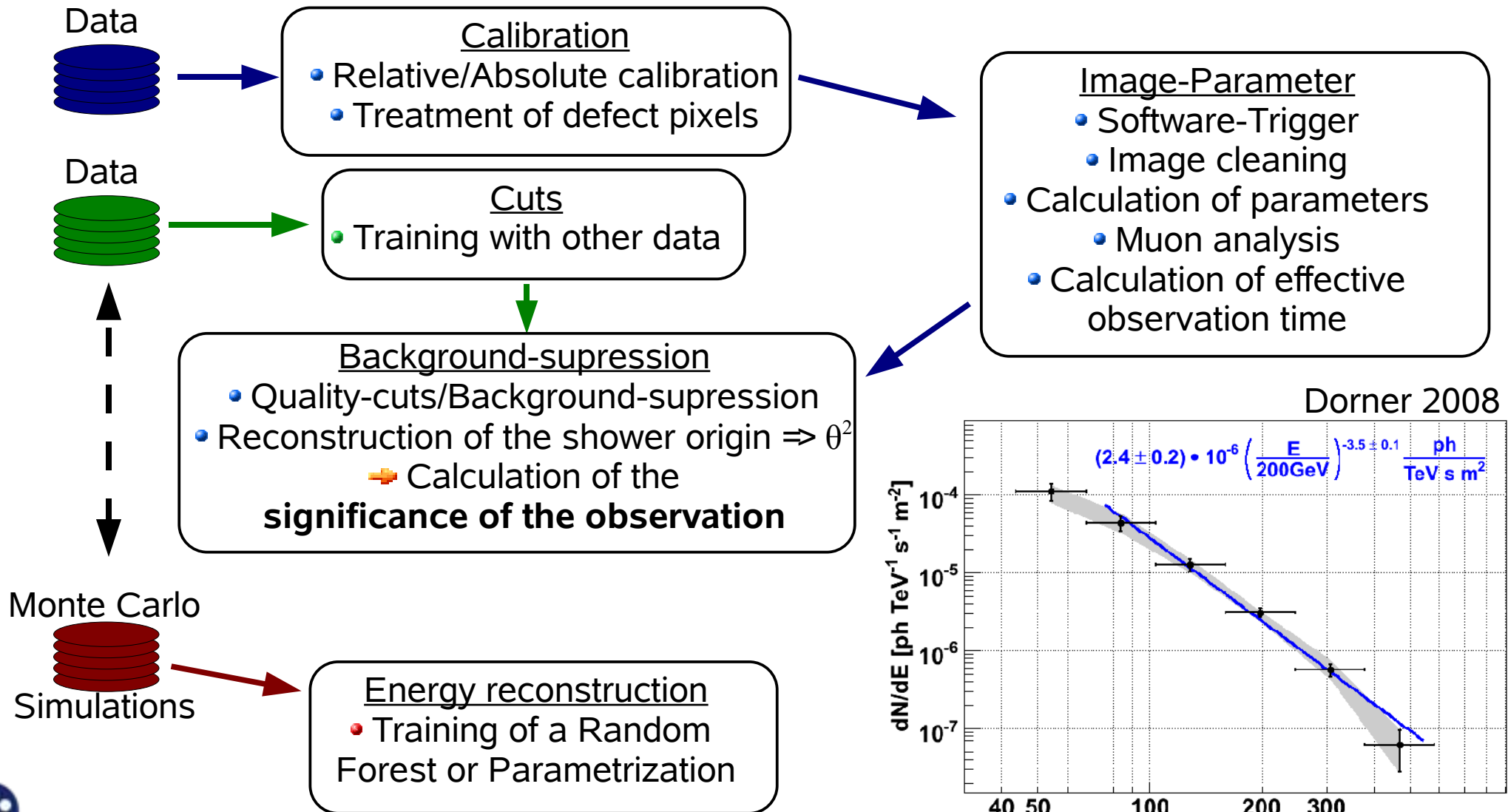


# Analysis Principles

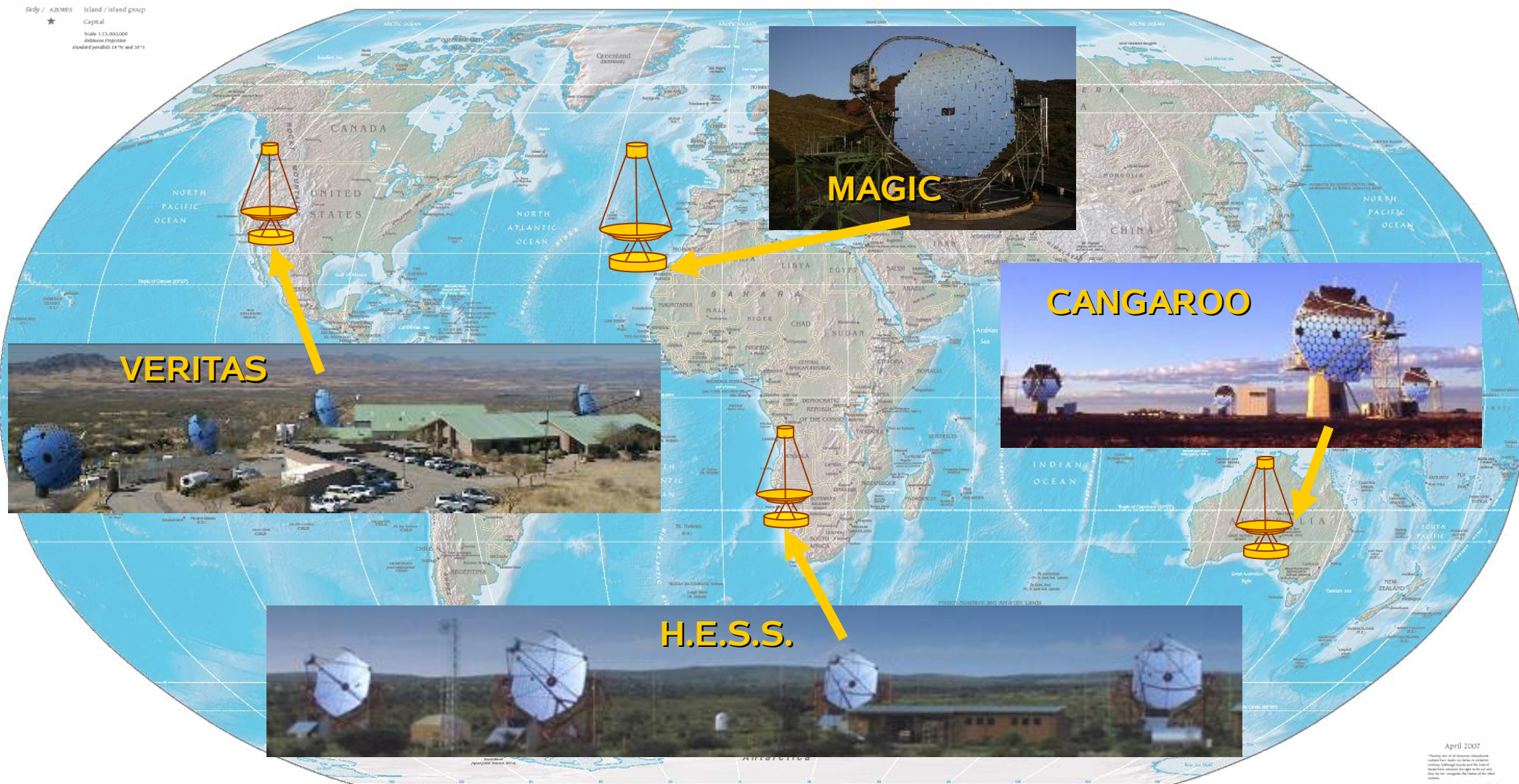




# Analysis Principles

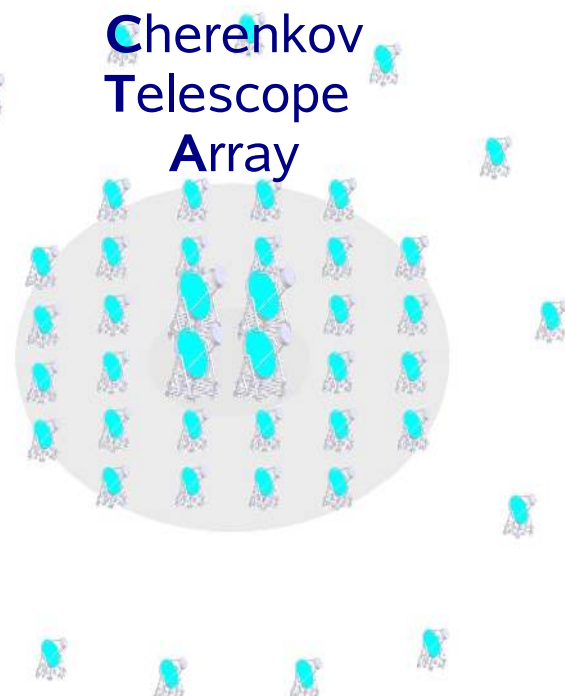


# Current Generation of Cherenkov Telescopes



# Future Cherenkov Telescopes

- Discovery of many new sources in wider energy range with improved sensitivity: **AGIS, CTA**





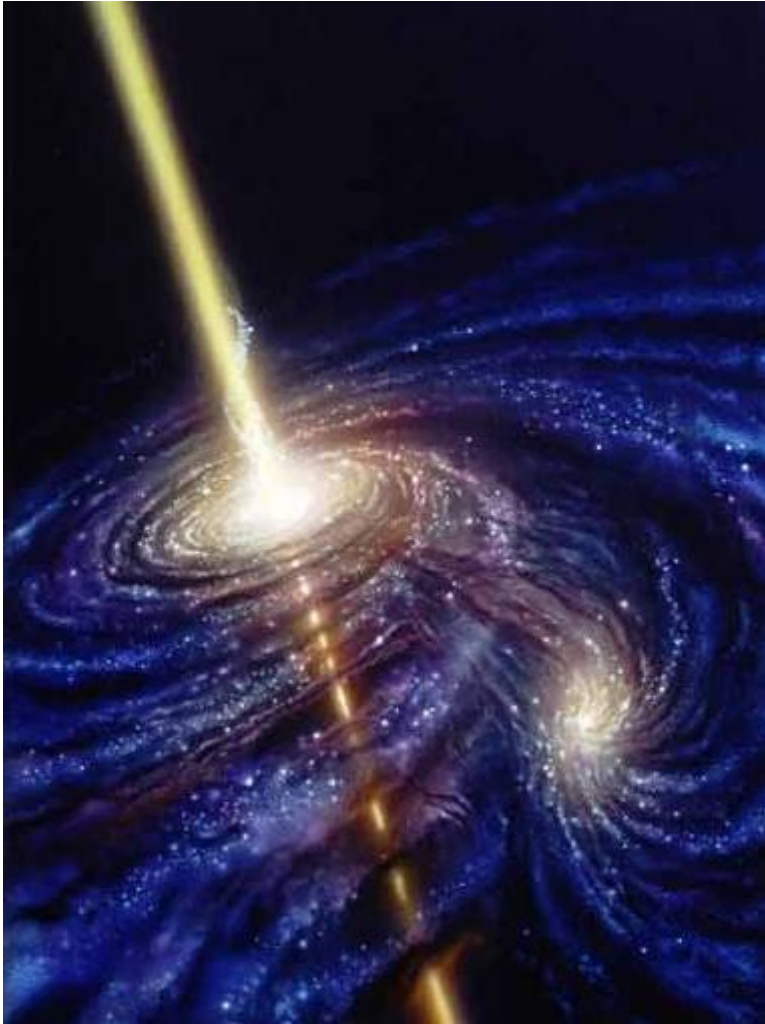
# Future Cherenkov Telescopes

- Discovery of many new sources in wider energy range with improved sensitivity: AGIS, CTA
- **Longterm monitoring of bright AGN: DWARF**



photomontage

# DWARF Project



## Active Galactic Nuclei

Extreme variability on time scales from minutes to years

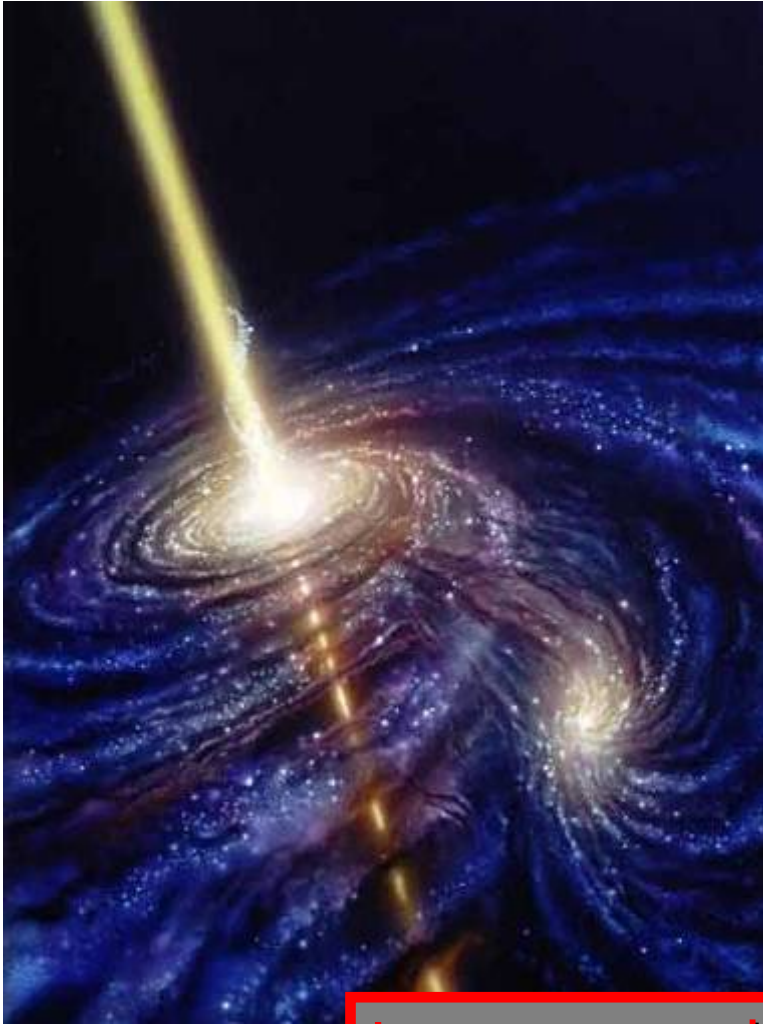
possible explanation e.g. binary black holes

Correlations between different wavelengths

=> better understanding of acceleration mechanisms

Especially correlations with neutrinos (IceCube), clear hadronic signature

# DWARF Project



## Active Galactic Nuclei

Extreme variability on time scales from minutes to years

possible explanation e.g. binary black holes

Correlations between different wavelengths

=> better understanding of acceleration mechanisms

Especially correlations with neutrinos (IceCube), clear hadronic signature

**Long-term observations mandatory!**



# DWARF Project

HEGRA CT3 at La Palma



## The idea

Affordable **monitoring telescope** observing only a few target objects: Mkn421, Mkn501, 1ES 1959+650, 1H 1426+480, PKS 2155-304, 1ES 2344+514 with **large duty cycles**

**Refurbish** one of the former HEGRA telescopes switched off since ~2002  
CT3 still at La Palma

# DWARF Project

HEGRA CT3 at La Palma



DWARF





# DWARF Project

## Upgrade telescope:

Will be **operated remotely**

40 mirrors from HEGRA CT1 hexagonal after refurbishment: slightly larger mirror area, **improved reflectivity**

## **New type camera**

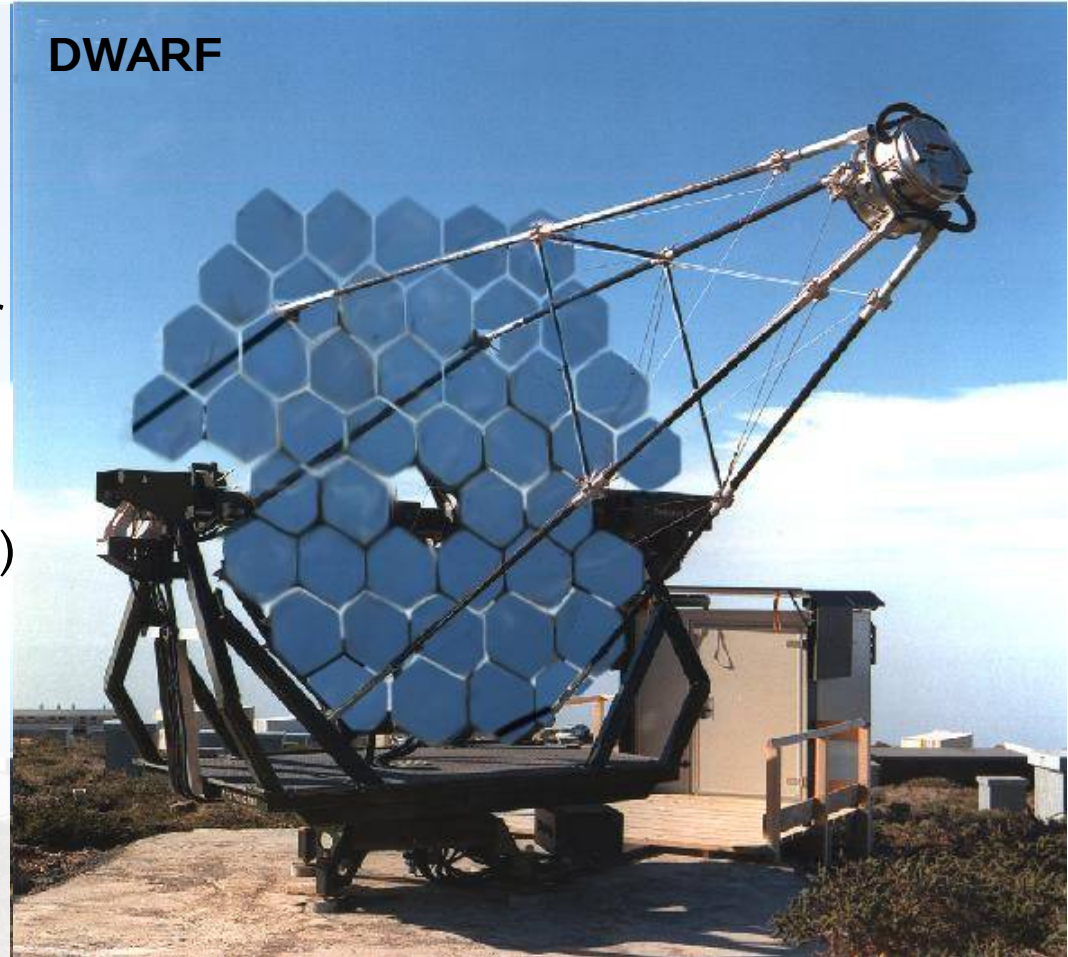
Semi-conducting photosensors (G-APDs)

Compared to PMTs: **better photon detection efficiency, robustness**

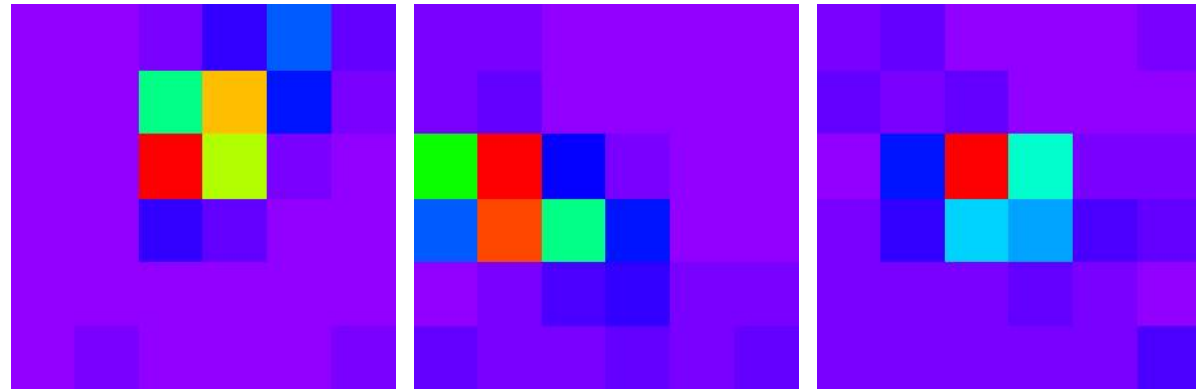
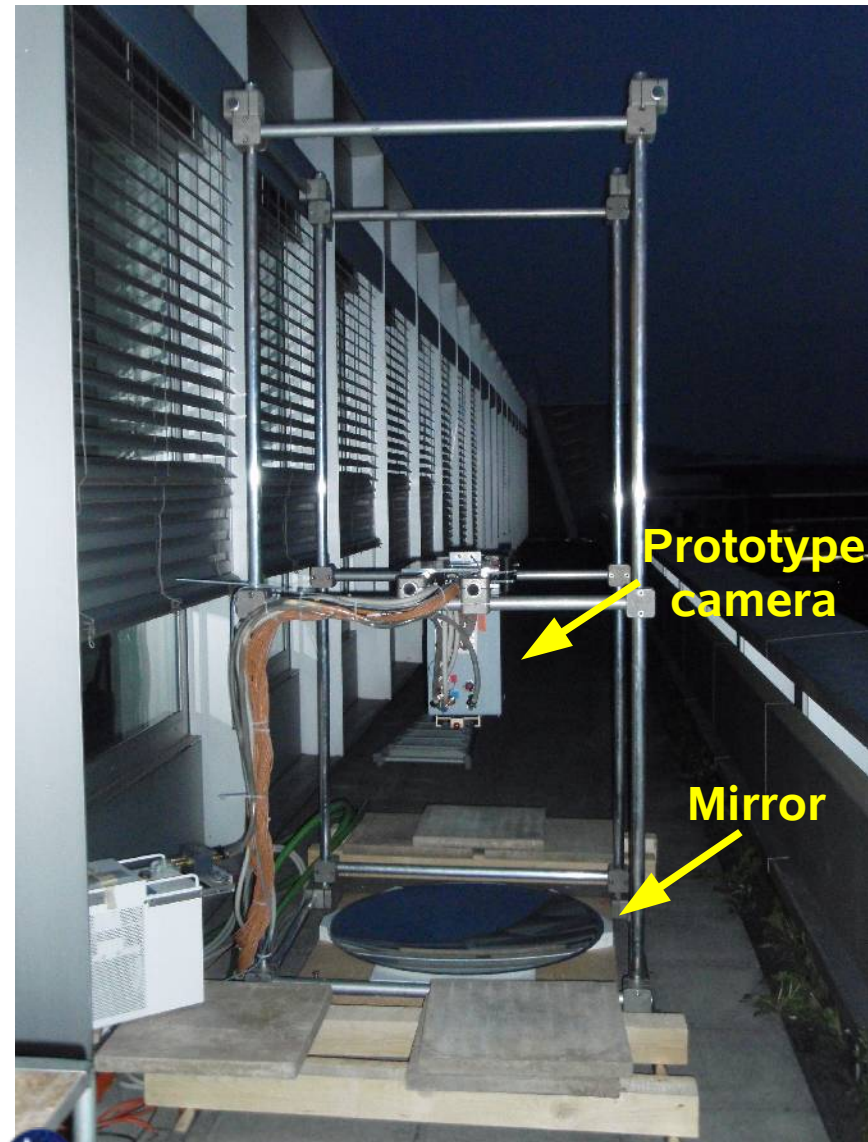
Use of solid cones under investigation

Design ready end of the year,  
camera finished in 2010

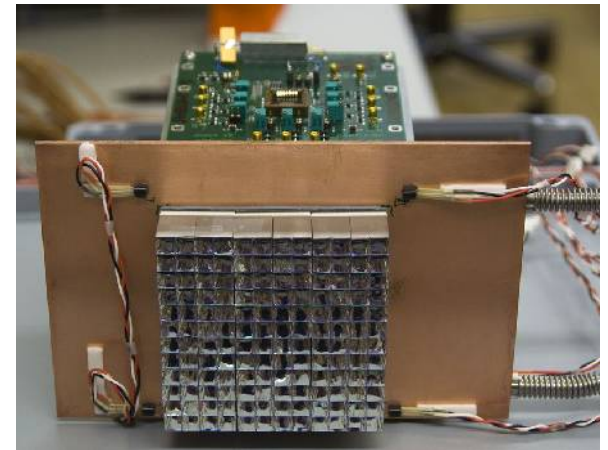
DWARF



# DWARF Project



Anderhub et al. submitted to JINST



Prototype:

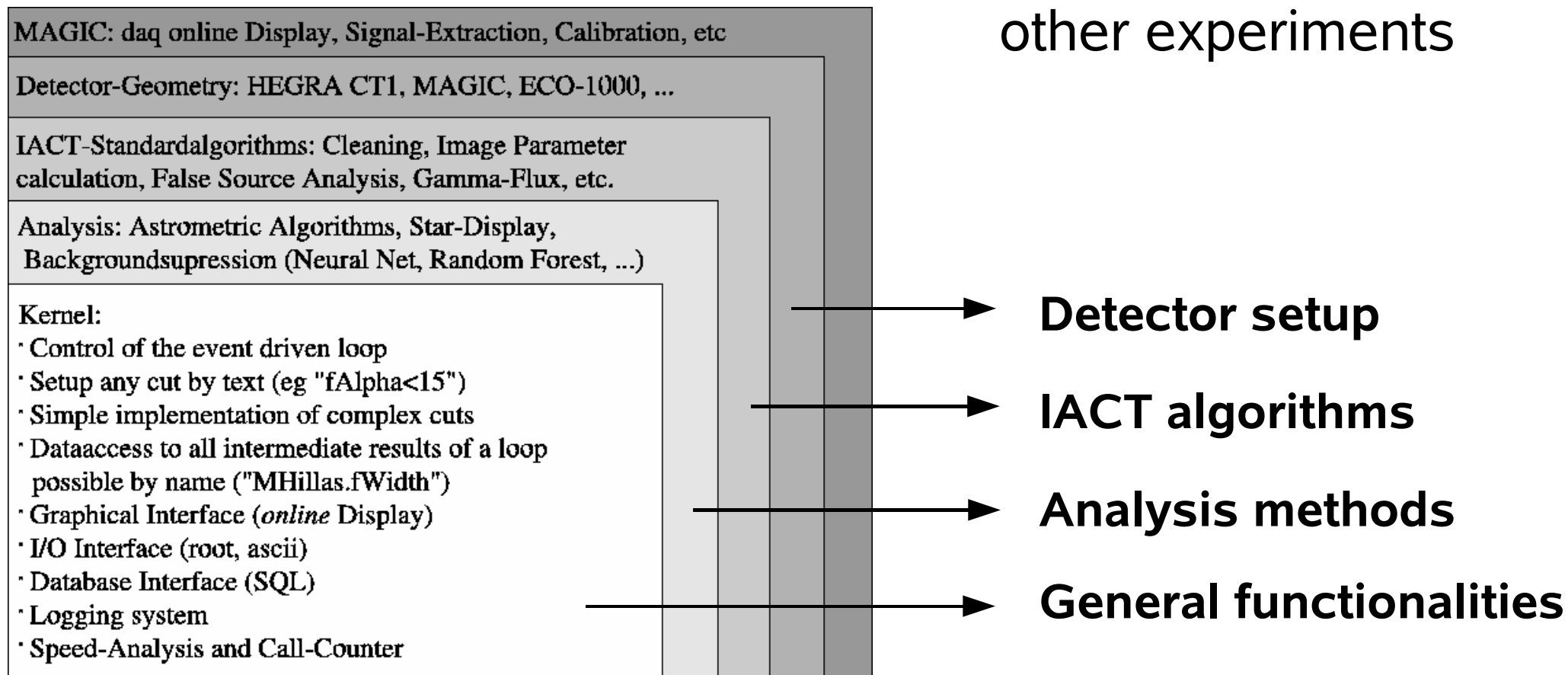
**First shower images successfully recorded**  
Extensive lab-investigations ongoing

# MARS – CheObs ed.

## Software: Layer Architecture

=> **Flexibility**

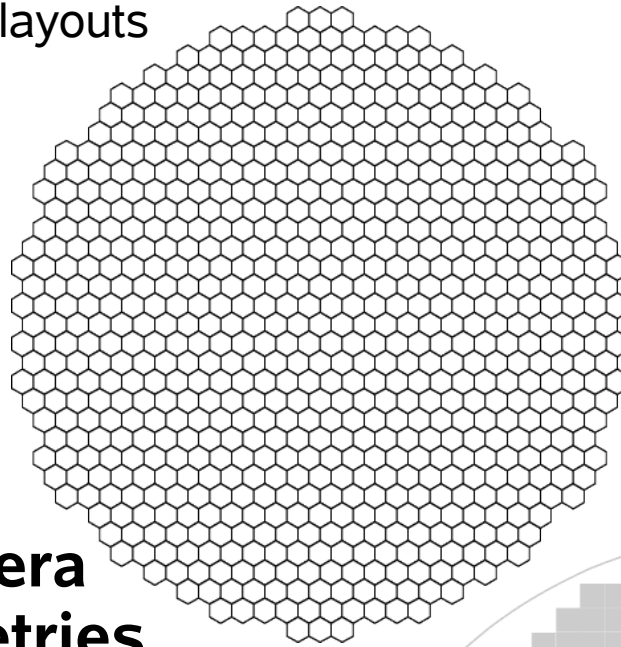
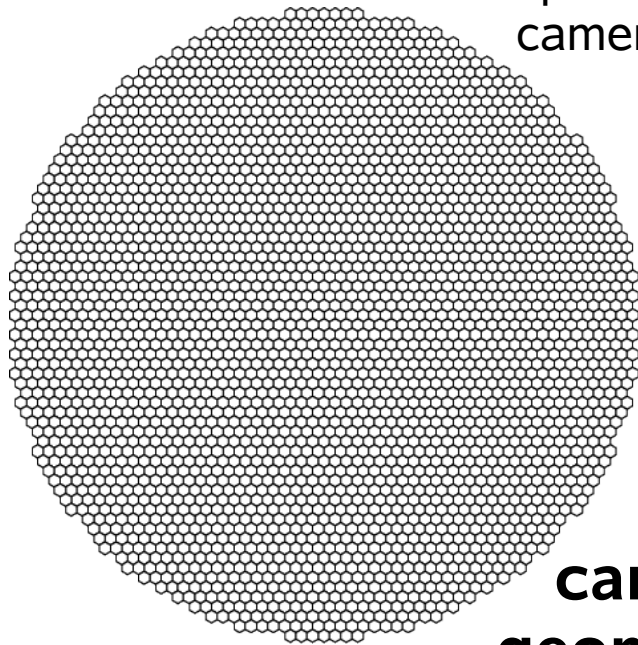
=> usable also for other experiments



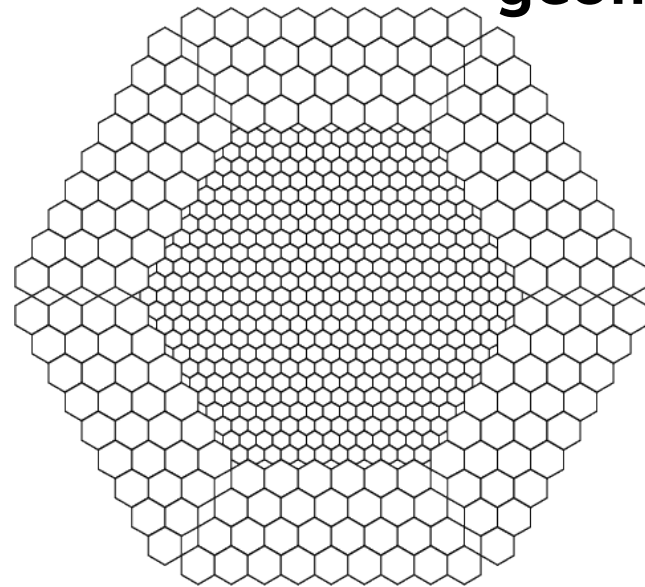
Bretz, AIP Conf.Proc. 745, 2005



two possible DWARF  
camera layouts

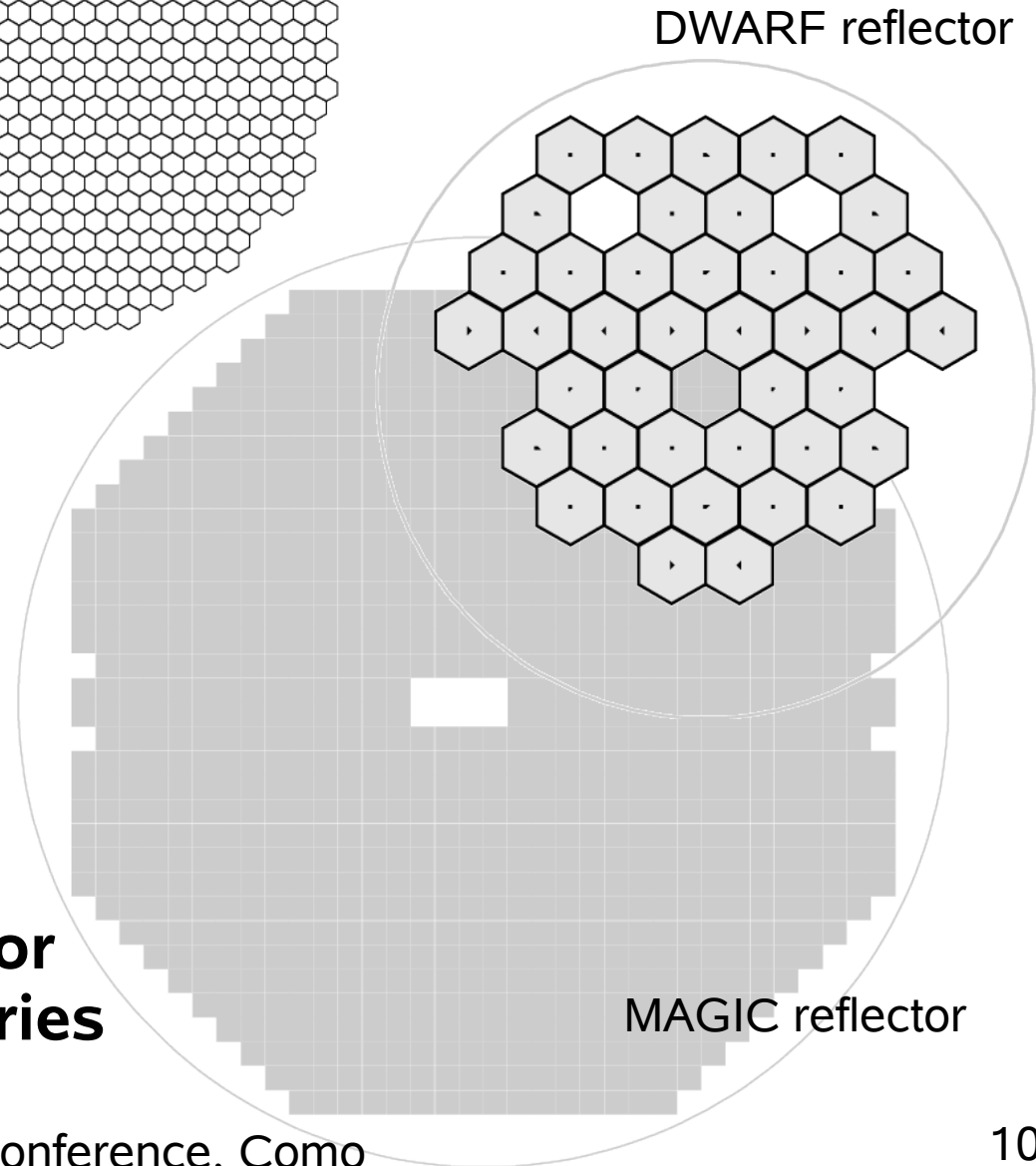


**camera  
geometries**



MAGIC I camera

**reflector  
geometries**



DWARF reflector

MAGIC reflector

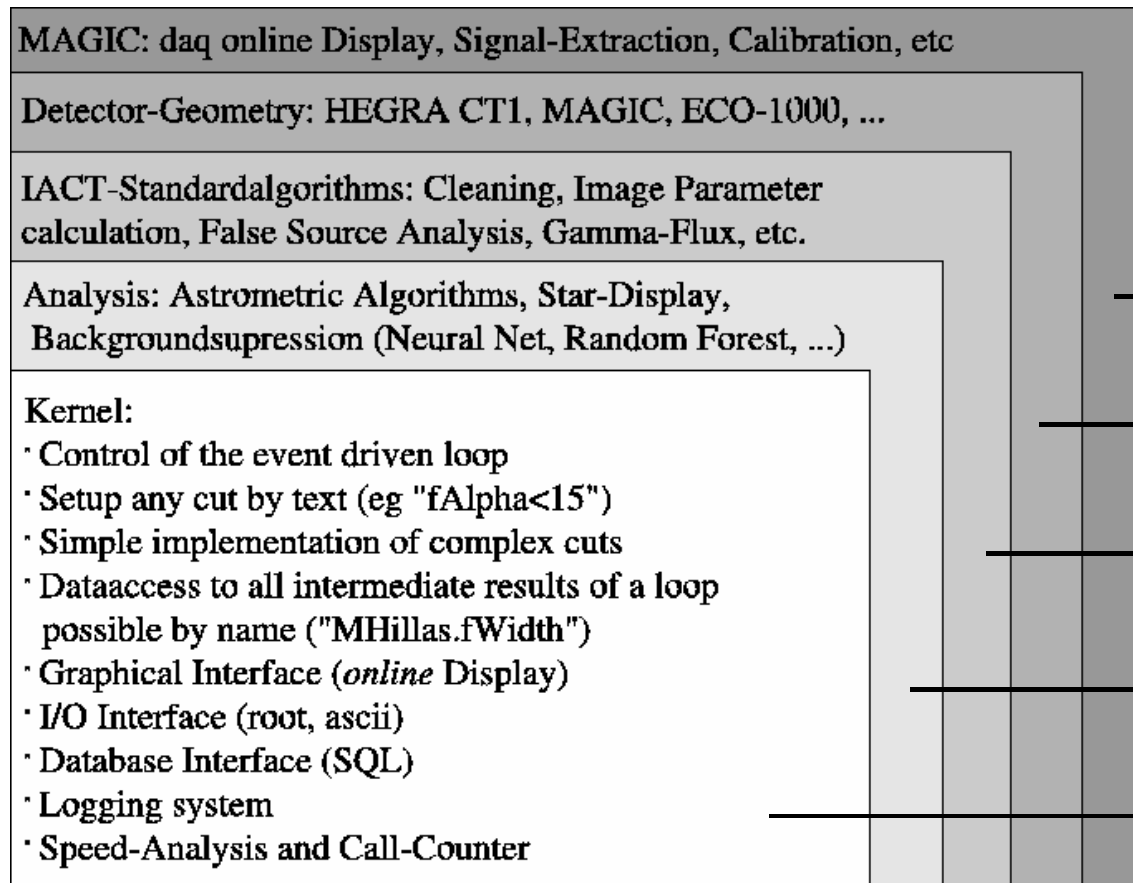
## Detector Setup

# MARS – CheObs ed.

## Software: Layer Architecture

=> **Flexibility**

=> usable also for other experiments

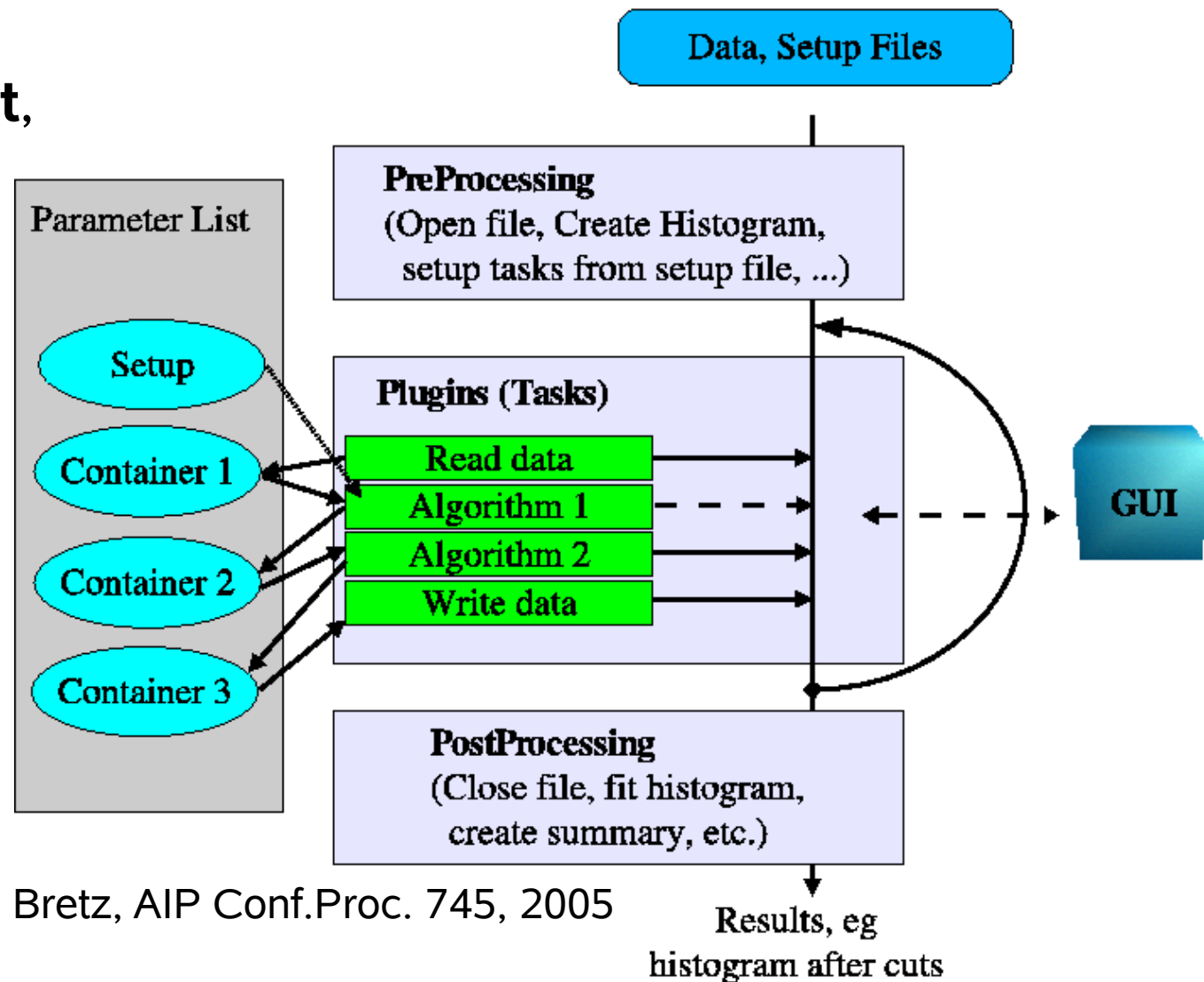


Bretz, AIP Conf.Proc. 745, 2005



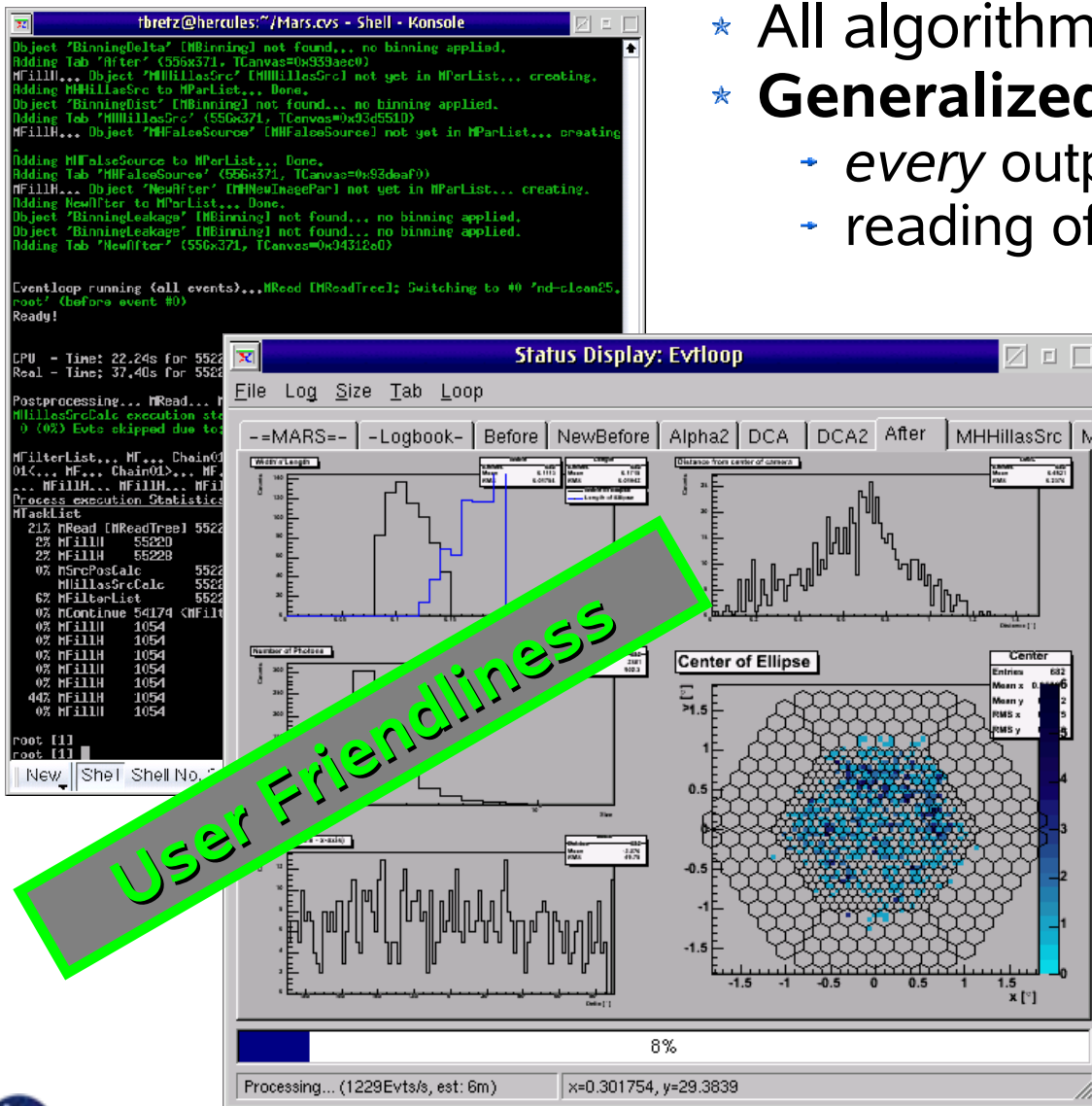
# MARS – CheObs ed.

- **Plugin-Concept:**
  - **Easy enhancement,**  
e.g. new algorithms



# MARS – CheObs ed.

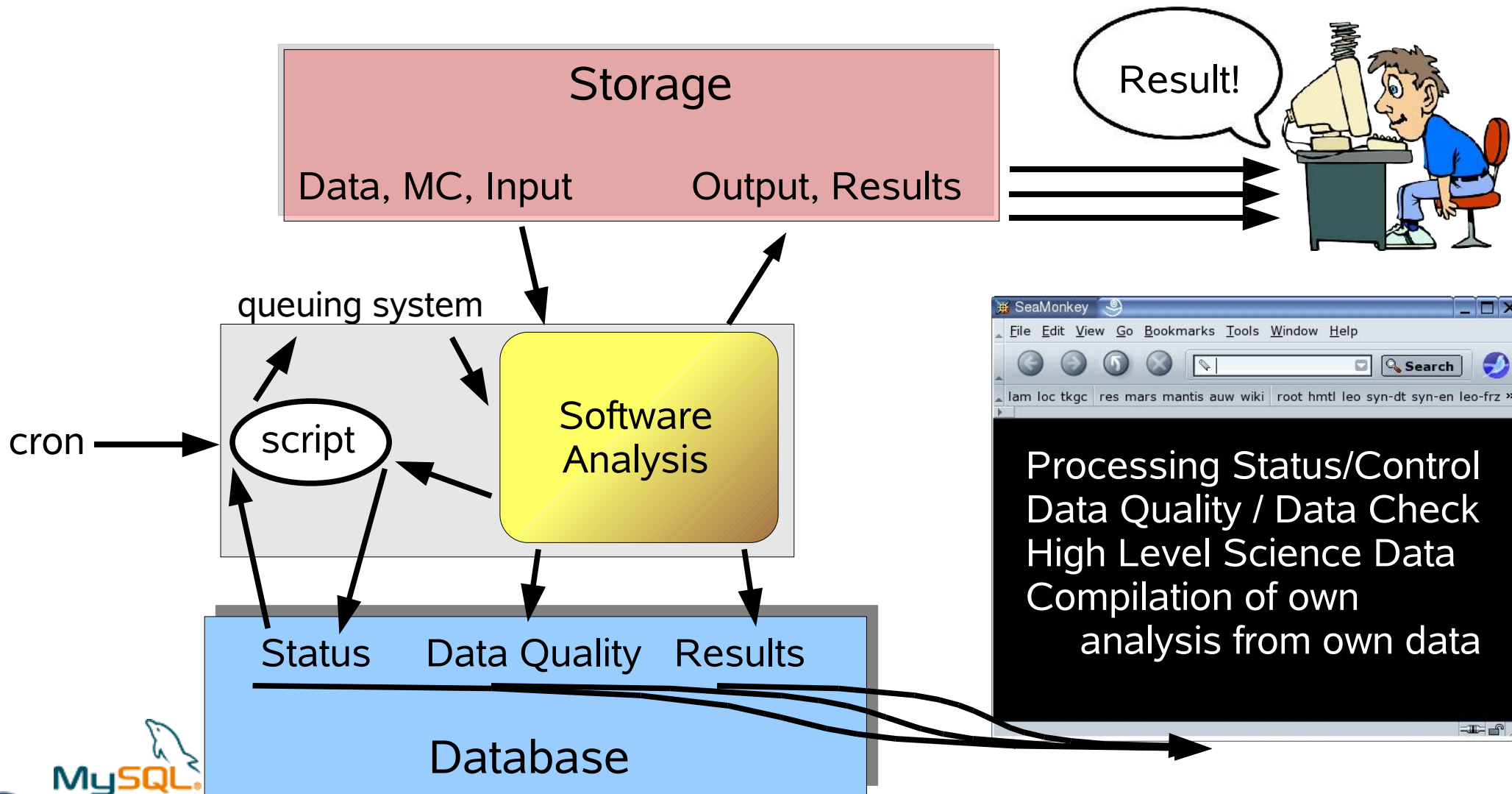
- ★ All algorithms telescope- / data- **independent**
- ★ **Generalized** I/O (for all data), e.g.
  - every output is easily implemented
  - reading of different data format is very easy



- ★ Very **flexible** logging stream
- ★ **Online display** (tracing)
- ★ Histogram classes
- ★ Debugging (runtime, calls, etc)
- ★ Generalized resource-files
  - Easy to implement
  - *Standardized*
  - Very **powerful**
- ★ Complete(!) setup is stored in output file (**reproducibility**)

# MARS – CheObs ed.

Package includes **automatic processing**



# Simulations for DWARF

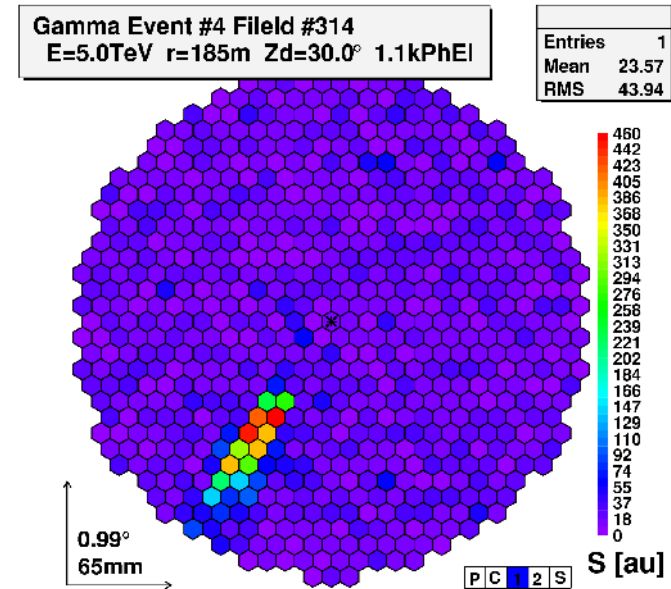
MARS – CheObs ed.:

Simulations for DWARF: **ceres**\*

Simulation studies for optimizing  
the camera properties

Comparison of several trigger types

More than 50 triggers simulated  
Sum trigger performs clearly best



\* Camera **E**lectronics and **R**Eflector **S**imulation

# Simulations for DWARF

MARS – CheObs ed.:

Simulations for DWARF: **ceres**\*

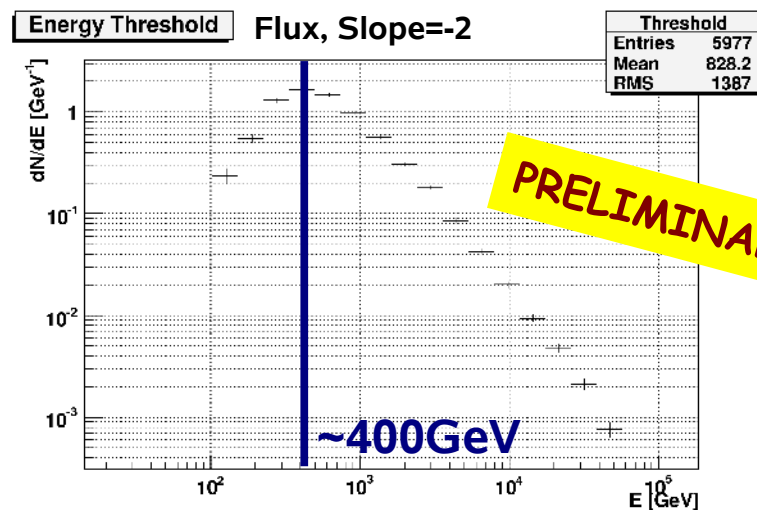
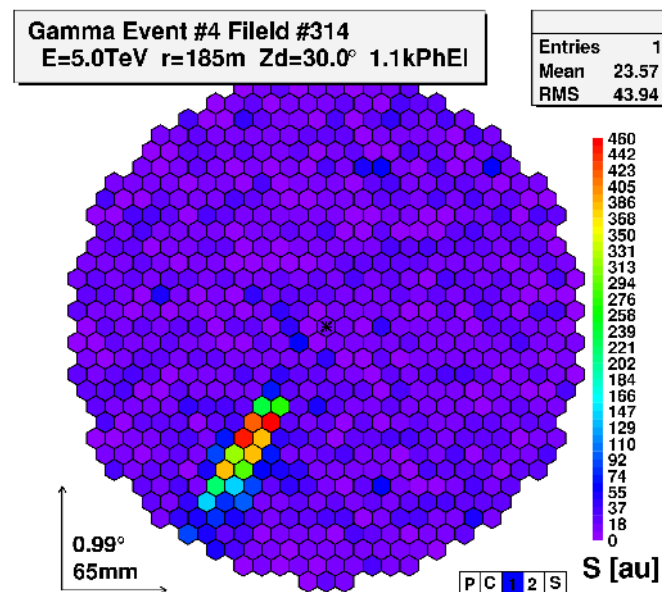
Simulation studies for optimizing  
the camera properties

Comparison of several trigger types

More than 50 triggers simulated  
Sum trigger performs clearly best

All simulations show promising  
results with an energy threshold  
(flux peak energy) around 400GeV  
for reconstructed images

\* Camera **E**lectronics and **RE**flector **S**imulation





# Conclusions

- MARS – CheObs ed.:
  - Flexible and userfriendly software package not only for Cherenkov telescopes
  - New: includes package for simulation of IACTs
  - Used for DWARF, MAGIC and CTA
- DWARF:
  - Successfully recorded first shower images with prototype camera FACT
  - Simulations very promising for physics goals

# Outlook

- MARS – CheObs ed.:
  - Implementation of stereo analysis
- **Dedicated Worldwide AGN Research Facility**
  - Network of small Cherenkov telescopes around the globe
  - 24/7 monitoring
  - Starting point: collaboration with Whipple 10 m

